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PHYSICAL CHEMISTRY.—*Stabilized free radicals.*[1]

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There has recently been a great surge of interest in the subject of stabilized free radicals. Chemists, rocket engineers, physicists, even biologists and astronomers are all interested, and persons from each of these varied disciplines are doing free radical research.[3] In each of these fields there is the anticipation that the relatively new techniques of stabilizing at low temperatures molecular fragments that are extremely reactive at normal temperatures will shed light on problems which had not yielded to other techniques. There is also the hope that we will be able to produce energy rich mixtures for fuel application and perhaps stabilize new and interesting compounds with free radicals at low temperatures.

There are many ways of producing and stabilizing free radicals. One class of methods involves providing energy to a suitably chosen gas, while the gas is en route to a surface that is maintained at a very low temperature-liquid nitrogen to liquid helium temperatures or thereabouts. If the energy is great enough to break chemical bonds in the gas and produce reactive molecular fragments (i.e., free radicals), some of them will, upon condensing on the cold surface be surrounded by inert species. In this event, as diffusion can hardly occur at such low temperatures, radicals trapped in this way will stay where they are. They will be able to react only when the temperature is increased and they can break out of their trap. To provide sufficient energy to break up the gas molecules any one of a large number of methods may be used. Among the more commonly used ones are (1) microwave discharge [*1*, *17*], (2) photolysis [*17*], and (3) heat [*22*, *23*].

One may also produce and trap free radicals by irradiating a solid which is kept at low temperatures. Any sufficiently energetic radiation will do the trick—X-rays, electrons, protons, neutrons, γ-rays, etc., i.e. [*11*, *16*, *19*, *26*]. If the solid is kept sufficiently cold the free radical produced in this way may find a site where it is surrounded by inert species and remain trapped there indefinitely as long as the temperature is kept low enough.

To observed stabilized free radicals and obtain information about them, every known property of the free radical is being exploited. Absorption and emission spectra in all frequency ranges have been taken and analyzed in order to try to identify the species present. Calorimetric experiments are being performed to measure the amount of chemical energy stored in free radical mixtures. Warmed up free radical mixtures are chemically analyzed to look for clues as to what free radicals were present at low temperatures. Measurements of electric and

[1] An address before the Advanced Propulsion Systems Symposium, Los Angeles, Calif., December 1957.

[2] This work was performed under the National Bureau of Standards Free Radicals Research Program, supported by the Department of the Army.

[3] As examples of published work in these fields, we may note the following examples: physics-references [*1*, *13*, *15*]; chemistry-references [*11*, *22*, *23*]; rocketry-references [*2*, *25*]; astronomy-reference [*9*]; biology-reference [*8*]. An excellent review of the stabilized free radical field is contained in reference [*3*]. Italic numbers in brackets above and in the text refer to the papers listed in the bibliography at the end of the paper.

magnetic susceptibilities are being performed.

One of the most important of detection techniques is that of electron spin resonance, wherein the absorption of microwave energy by a sample is observed as a function of an externally applied magnetic field. The detailed shape of this magnetic absorption spectrum carries the "signature" of the radical that absorbs the radiation, which enables one to identify the species. Free radicals, in general, have unpaired electron spins and thus have large net magnetic moments. The gross absorption of energy is due to the flipping of the magnetic moment of the unpaired electron from a low energy state parallel to the magnetic field to the higher energy state in the opposite direction. The fine details in the absorption are due to the interaction of the electronic magnetic moment with the smaller magnetic moments of the nuclei of the free radical.

PERCENTAGES OF RADICALS OF SPECIES TRAPPED

These techniques have already provided us with important information. Some of the most impressive results are the positive identifications of large varieties of free radical species. Spectral lines from free radical mixtures of oxygen and nitrogen have quite convincingly been identified as atomic oxygen and atomic nitrogen lines. Among the simpler free radicals that have been identified by spin resonance techques there are the hydrogen atom [*15*, *16*], the nitrogen atom [*7*, *10*] and the methyl radical [*11*, *19*]. Many more complicated organic free radicals have also been identified.

There are still, however, formidable problems involved in the full explanation of the properties and composition of stabilized free radical mixtures. More precisely, although we can say in some cases that such and such a free radical is present in a mixture condensed at low temperatures under given circumstances, we cannot as yet give a full account of all of the species present and of their numbers.

The question of the number of free radicals stabilized is not only of prime importance from the viewpoint of possible fuel applications but is also basic to our understanding of what is happening. Precise measurements of free radical concentrations are extremely difficult and due to uncertainties in the kinds of chemical species present, often do not lead to unambiguous interpretations. Thus most of the results obtained are to be regarded as the best estimates of the experimenter—estimates based upon his best guess as to what is happening. In the following table are listed some of these estimates for stabilized atomic free radicals. Most of the experiments listed in the table were done at liquid helium temperatures. The percentages given are the molar percentages, i.e., 1 percent H atoms means 1 hydrogen atom for every 99 hydrogen molecules. The figures given in the table are generally conservative ones, which means low in all cases but the sixth experiment listed, where the figure is Dr. Harvey's upper limit. It should be emphasized that this "conservative" estimate is always on the basis of the particular physical assumption of the experimenter and if one does not agree with this assumption one can get far different values.

The calorimetry method involves a direct measurement of the amount of energy stored in the deposited mixture. To obtain a figure for the number of free radicals one must know what processes give up this energy. If one assumes that all of the energy yield is due to the recombination of nitrogen atoms or oxygen atoms, respectively, one obtains an estimate for the number of free radicals; by metering the gas flow an estimate of the concentration is obtained. In the most recent work of Minkoff and Scherber, they measure the difference in the amount of heat needed to bring the deposited mixture up to a given temperature for two cases—first with no discharge and then when the gas passes through a discharge. The difference is presumably the energy stored by the free radicals. The range in their oxygen atom determination is due to the different reactions possible. If one assumes that the energy is released as a result of ozone formation one gets the larger figure, about 16 percent; assuming that we have oxygen molecule formation the number is of the order of 6 percent.

When oxygen is passed through a discharge and collected at 4°K, it forms a colorless deposit which turns violet upon heating. If one recovers the gases after warming up the deposit and analyzes them one finds that much ozone has been produced. The assumption is that O atoms are trapped in the deposited mixture and that during warm up they migrate and combine with O_2 to form ozone. Assuming simple chemical kinetics after warmup, Ruehrwein computed back to the initial oxygen atom concentration from the measured ozone yield.

Contradicting this evidence is the work of Harvey, who finds little or no increase in ozone concentration, as measured by infrared absorption, when the oxygen deposit is warmed. He obtains the indicated figure 3 percent as an upper limit for the trapped oxygen atom concentration.

The spin resonance estimates are obtained from the intensity of the absorption lines as well as from the line broadening which can be related to concentration.

The last row, it should be noted, involves the irradiation of a solid at low temperatures. The figure quoted is the saturation value, the apparent maximum that can be produced by irradiation.

Although there are apparently many contradictory indications in the table, there is really more agreement than meets the eye. If one takes into account the fact that the experiments of Broida and Lutes were earlier ones, indeed the first experiments of their kind, and subject to greater errors, their results are not difficult to reconcile with those of Minkoff and Scherber. Indeed, they both agree that one gets higher oxygen concentrations than nitrogen concentrations. The result that does appear incompatible with the others is Harvey's negative result with respect to increase of ozone absorption.

What are the possibilities of increasing these percentages and how could one go about doing this? Two methods have been suggested, (1) adding an inert diluent and (2) depositing in a strong magnetic field.

The idea of adding a diluent is that inert atoms could serve as buffers between reactive free radicals. Preliminary indications are that this is true and one can get higher percentages of free radicals this way—that is if one computes the free radical percentage as the ratio of atomic free radicals to molecules made up of those atoms. If one computes the free radical percentage as a fraction of all species present, counting the diluent atoms, one apparently does not get an increase. The results, however, are not yet conclusive.

If one considers two hydrogen atoms coming together they can form a stable molecule only when their spins are in opposite directions. If there is no magnetic field present, there is no energy difference between two atomic spin states and they will be able to adjust without trouble if they are unfavorably aligned initially. Putting the system in a magnetic field creates an energy difference between the spin up and spin down states. If initially their spins are aligned unfavorably for molecule formation, it takes energy to get them to flip their spins

TABLE 1.—FREE RADICAL CONCENTRATIONS

Detection method	Method of producing radicals	Species	Estimated percentage	Research group
(1) Calorimetry	Microwave discharge	N	.2	Broida and Lutes [5]
(2) Calorimetry	Microwave discharge	N	6.0	Minkoff and Scherber [20]
(3) Calorimetry	Microwave discharge	O	1	Broida and Lutes [5]
(4) Calorimetry	Microwave discharge	O	6–16	Minkoff and Scherber [20]
(5) Chemical analysis	Microwave discharge	O	15	Ruehrwein, Edwards, Hashman [24]
(6) Infrared absorption	Microwave discharge	O	3	Harvey [12]
(7) Spin resonance	Microwave discharge	H	.1	Jen, Foner, et al [14, 15]
(8) Spin resonance	Irradiation of $HClO_4$ and H_2O	H	.01–.1	Livingston, et al [16]

before they can form a molecule. Thus if the system is in a magnetic field, the process of molecule formation may be retarded.

The energy difference between spin up and spin down states is $2\mu_0 H$, where μ_0 is the Bohr magneton, 1.86×10^{-20} ergs/gauss. If the system is at T°K, then the field which produces a magnetic energy difference of the same order of magnitude as the thermal energy is given by setting the magnetic energy equal to kT (where k is Boltzmann's constant 1.38×10^{-16} erg/degree Kelvin). The result is $H \sim 7400T$. For such a method to be effective in increasing free radical percentages one clearly needs high fields and low temperatures. Regardless of the possible uses of such an arrangement it would be interesting scientifically if such an experiment were tried.

On the basis of spectroscopic studies of the emission from condensed mixtures during warmup we are obtaining indirect evidence that odd molecular species are being stabilized. When experiments are done with nitrogen one observes a group of green lines which can be attributed to the ^2D-^4S transition of atomic nitrogen [*1*, *4*, *13*]. In the same experiment, when there is a small amount of oxygen impurity present, lines are seen in the warmup which can be attributed to the ^1S-^1D electronic transition of atomic oxygen [*21*]. The question is, why should one observe excited atomic lines in the warmup. The nitrogen transition in the gas state has a very long natural lifetime, calculated to be about 20 hours. In a solid, its lifetime should be much shorter, of the order of seconds, depending on the symmetry of its site. The oxygen transition, however, has a natural lifetime of only 0.9 second. In actual experiments performed, the deposited material has been kept cold for times much longer than this and even so what is thought to be the ^1S-^1D transition is still observed in the warmup. Indeed there seems to be no relationship between the length of time the free radical mixture is kept at liquid helium temperature and the subsequent intensity of the line during warmup.

How does one explain this phenomenon? Can one freeze in an electronically excited state of an isolated atom? The answer, on the basis of quantum mechanics is an unequivocal no. How then can one account for what one sees? During warmup, trapped atoms may become mobile and recombine. This process yields large quantities of energy, more than the energy needed to cause the electronic excitation of an atom. Although this is energetically possible, it seems like a most unlikely route for the energy to take. The most interesting hypothesis is that excited but metastable molecules are being trapped and stabilized. According to this hypothesis, only when the temperature becomes hot enough for the molecule to break up will the atom be able to radiate. Quantum mechanically, this is possible. Of course, this too, seems like a very unlikely kind of thing to be actually happening and there are as yet no detailed theoretical calculations indicating the stability of whatever molecule the oxygen atom may be a part of. However, the experimental results, too, are very unlikely and whatever the accepted explanation ultimately will be, it will certainly be one that will appear strange at first.

In conclusion, it should be emphasized that only a small number of the interesting results and new problems in the free radical field were discussed. Most free radical experiments, at this stage of the game, yield great quantities of unexplained data. On strictly a priori grounds, merely by virtue of the fact that so much is still so strange and so puzzling, the indications are that free radical experiments are going to teach us much that is new and much that is important about physical chemistry.

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Man is preeminently a creative animal, predestined to strive consciously for an object and to engage in engineering—that is, incessantly and eternally to make new roads, wherever they may end.—FEODOR DOSTOEVSKI.

ENTOMOLOGY.—*Two new species in the genus* Armigeres *Theobald, 1901, from northern Thailand (Diptera: Culicidae).*[1]

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During an investigation of the species of vectors and potential vectors of malaria and other mosquito-borne diseases in northern Thailand in connection with the expanded malaria and filariasis control program being conducted in that nation, two undescribed forms of *Armigeres* Theobald, 1901, were found. Though the descriptions are based on single female specimens, the characters as noted are not those of the currently recognized species of *Armigeres*.

Armigeres (Armigeres) bhayungi, n. sp.

Female medium sized, 5 mm. Palpi, proboscis, and tarsi dark, unbanded. Clypeus bare. Posterior pronotal lobes with dorsal patch of narrow dark scales. Sternites, propleura, and forecoxae white scaled.

Head: Proboscis, palpi, and clypeus dark. Palpi one-sixth length proboscis. Clypeus bare. Torj with white scales on inner and dorsal surfaces. Vertex with flat metallic blue scales, flat creamy scales in midline on basal half; few upright dark scales at nape; eye border of flat creamy scales contiguous with lateroventral white patches.

Thorax: Mesonotum with narrow, dark, metallic blue scales; creamy scales form border from front to wing roots; anterior pronotal lobes and posterior pronotal lobes with flat white scales, with few narrow, curved dark scales and dark setae on dorsal portions; propleura and forecoxae white scaled; patches on pleura white; two lower mesepimeral bristles present; prescutellum and scutellum dark scaled; capitulum of halteres dark metallic blue; wings all dark scaled; forelegs dark with femora white beneath; midlegs dark with dark upper edge of femora increasing in width from base to apex on posterior surface; hind legs dark, femora white to apex on anterior and ventral surfaces.

Abdomen: Tergal scales dark brownish with blue metallic luster; small lateral semicircular patches of white scales; all sternites with white scales.

In general habitus *A. bhayungi* appears near *Armigeres jugraensis* (Leicester, 1908), *Armigeres malayi* (Theobald, 1901), or *Armigeres kuchingensis* Edwards, 1915, differing from the first by having a light border around the front of the mesonotum and having the forecoxae all white scaled, and from *A. malayi* by having a definite broad white mesonotal border to the wing bases and the clypeus bare. It differs from the last species by having dark blue metallic scales on the mesonotum and dark scales on the dorsal portion of the posterior pronotal lobes. In *A. kuchingensis* the forecoxae and the sternites III–VI may be all white scaled or show patches of bronzy scales, while sternite VII is dark with a subapical light band. In the holotype of *A. bhayungi* the forecoxae and all sternites are white scaled.

Holotype, female, USNM 63910. Male and immature stages are unknown.

Type locality: Tad Muey Falls on Doi (Mountain) Sutep, Chiengmai Province, Thailand, elevation 4,000 feet. A single female was netted by Manop Rattanapradith in a shady jungle area near Tad Muey Falls (DC & EB Thurman collection # M-545), February 15, 1953.

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[2] Sanitarian, Division of International Health, U. S. Public Health Service, assigned as Regional Malaria Control Adviser for Northern Thailand with the U. S. Operations Mission to Thailand, International Cooperation Administration. (Mr. Thurman died suddenly in Chiengmai after having served more than two years there. This manuscript was completed by the junior author.)

[3] Sanitarian (R), Division of Research Grants, U. S. Public Health Service, formerly assigned as Malaria Control Training Adviser with the U. S. Operations Mission to Thailand, International Cooperation Administration.

This species is named in honor of the late Dr. Luang Bhayung Vejjasastr, director general of the Department of Health, Ministry of Public Health of Thailand, in recognition of his outstanding achievements as a pioneer in the malaria control program in Thailand, and in appreciation for the privilege of having known him as a friend and coworker during our assignment in his nation.

Armigeres (Leicesteria) vimoli, n. sp.

Female medium sized, 5 mm. Palpi, proboscis, and tarsi dark, unbanded. Clypeus bare. Abdominal markings of white scales.[4] Light scales on thorax light yellow or drab white.

Head: Palpi dark, a little longer than one-half length of proboscis. Proboscis dark metallic blue with ventral line of bluish-white scales. Clypeus bare. Tori with white scales medially placed and few gray ones above. First flagellar segment with white scales. Occiput with dark blue scales, light yellow scales around margin of eyes,[4] in lateral patch, and at nape; few upright, forked, light scales at nape; lateral patch followed by dark patch; light scales under the head.

Thorax: Distinctly produced over the head; bronzy-brown, narrow curved scales on mesonotum; pale yellow, broad shaggy scales on front margin around to wing bases; drab tan scales over wing bases, in midline on prescutellum, and on mid and lateral lobes of scutellum. Posterior pronotal lobes with pale yellow, shaggy scales and a few light weak bristles. Upper portion of propleura with drab white scales, lower portion with black scales. All other pleura light scaled. Lower mesepimeral bristles absent. Capitulum of halteres dark scaled. Wing scales dark grayish brown, few tan scales at base of costa; posterior and anterior cross veins separated by the length of the latter. Legs: Forecoxae light scaled with central patch of black; femora dark above, white below; tibiae shorter than mid and hind tibiae, dark above, light below; tarsi dark. Midcoxae white scaled; femora dark anteriorly, few light scales in apical fringe, light underneath; tibiae dark above, light below; tarsi dark. Hind coxae white; femora dark on narrow dorsum, light on sides and beneath, tibiae dark above, light below; tarsi dark.

Abdomen: Tergites dark with scales of bluish metallic luster; subapical lateral white spots visible dorsally on tergites III–VI. Tergite VIII with basal white spot. Lateral markings all white. On tergite II lateral markings abruptly angles, on tergites III–VII not markedly concave, the upper margin being almost straight. Sternite II all white. Sternites III–VII with narrow apical dark bands (grayish brown); VIII all drab white scaled.

Holotype, female. USNM 63217. Male and immature stages are unknown.

Type locality: Doi (Mountain) Sutep, Chiengmai Province, Thailand, February 21, 1953 (Deed C. Thurman, Jr., DC & EBT collection #558). A single female was netted while flying over a small stream in a shady jungle valley, elevation 2,000 feet, near a rest cabin owned by an American Missionary, Dr. Richard Buker. This female was collected in association with specimens of *Armigeres annulitarsis* Leicester, 1908, *Armigeres longipalpus* Leicester, 1904, and *Aedes* spp. A second female which appears to be conspecific with *A. vimoli* was netted in the same location at the same time by Manop Rattanopradith; however, the specimen is damaged, and it is impossible to make a positive determination.

In habitus *A. vimoli* appears to be near *Armigeres digitatus* Edwards, 1914, or *Armigeres pectinatus* Edwards, 1914, though differing in the coloring and type of the scales on the posterior pronotal lobes, *A. vimoli* possessing pale yellow, shaggy scales while the other two species have white, flat scales.

It is a pleasure to name this species for Dr. Vimol Notananda, Malaria Control Officer in Chiengmai, a friend and coworker who is contributing much to the control of malaria in northern Thailand.

[4] Since the initial writing of the description, the specimen has become oily, and the white scales now appear yellowish. The scales around the eye margins are rubbed.

ICHTHYOLOGY.—*A new species of iniomous fish from the Gulf of Mexico.* GILES W. MEAD, United States Fish and Wildlife Service.

(Received April 14, 1958)

The iniomous family Aulopidae is composed of three genera. *Hime* includes *H. japonicus* (Günther, 1880: 72), which is known from various localities in the western Pacific, and *H. damasi* (Tanaka, 1915: 340), from Japan. The Australian *Latropiscis* includes two closely related species, *L. purpurissatus* (Richardson, 1843: 6) and *L. milesi* (Cuvier and Valenciennes, 1849: 521; roy. ed. p. 386). *Aulopus*, heretofore known only from the Mediterranean Sea and adjacent Atlantic waters, includes *A. filamentosus* Cloquet (1816: 128), *A. tirus* (Rafinesque, 1810: 56), *A. lacerta* (Risso, 1826: 463), *A. filifer* Valenciennes (1836: 73), *A. maculatus* Valenciennes (1836: 74), *A. cadenati* Poll (1953: 81) and the new species described below. Although *Aulopus lacerta*, *filifer* and *maculatus* are conventionally included within the synonymy of *A. filamentosus*, such allocation is questionable. Not all of the differences among the published descriptions can be attributed to sexual dimorphism. Material which would permit a review of the eastern Atlantic forms is not now available.

I am indebted to G. E. Maul of the Museu Muncipal do Funchal, Funchal, Madeira; Dr. Enrico Tortonese, Museum of Natural History, Genoa, Italy; and Dr. Max Poll, Musée Royal du Congo Belge, Tervuren, Belgium, for comparative specimens of *Aulopus filamentosus* and *A. cadenati* from off Madeira, Italy, and equatorial Africa.

Aulopus nanae, n. sp.

(Fig. 1; Table 1)

Holotype: A male specimen 223.0 mm in standard length caught in the Gulf of Mexico off Tortugas, Fla., by the United States Fish and Wildlife Service exploratory vessel *Oregon* at station number 1025 (April 19, 1954; 25° 12′ N. lat., 84° 05′ W. long.; 75 fathoms; 40-foot flat shrimp trawl). USNM 158985.

Diagnosis: Similar to the eastern Atlantic *Aulopus filamentosus* but differing principally in the number of predorsal scales (12 *cf.* 15–16 in *A. filamentosus*), number of scales in lateral line (48 *cf.* 52), number of vertebrae (48 including the hypural *cf.* 51–52), the width of the bony interorbital (3.6 percent of standard length *cf.* 4.1–5.0 percent), the length of the ventral fin (27 6 percent *cf.* 19.6–25.6) and the length of the anal fin, the last ray of which is much longer than the depth of the fish measured at origin of anal fin (15.2 percent of standard length *cf.* 7.6–9.6 in eastern Atlantic *A. filamentosus* males; 7.7 in *A. cadenati*).

Description: The counts and proportional measurements of the single known specimen of *Aulopus nanae* are given in the first column of Table 1.

Body subcylindrical, broadest at origin of pectoral fin. Snout depressed, the ventral profile nearly straight from tip of lower jaw to caudal peduncle. Body deepest at origin of dorsal fin, this depth 1.8 in length of head. Depth of body at origin of anal fin 2.6 in head; least depth of caudal peduncle 4.5 in length of head.

Top of head, snout and mandible naked. Cheeks, opercles, body and base of caudal fin scaled. Lateral line complete, terminating over base of micaudal ray and formed of scales each of which bears a simple tube but is otherwise similar to the scales adjacent to the lateral line. Scales on head and sides of body ctenoid, those on ventral surface cycloid. Body scales relatively large and imbricate, the cteni numerous and irregular in size. Scales in axil of pectoral fin lacking cteni and more closely imbricate than body scales but of similar size and shape. Scales in axil of pelvic fin vertically elongate but not greatly enlarged.

Length of head 3.3 in standard length. Length of snout 3.6 in length of head; lower jaw terminal. Nostril located about two-thirds of distance from tip of snout to anterior edge of orbit. Septum between anterior and posterior nostril with a simple cirrus, the length of which is about one-half the width of the bony interorbital. Eye irregularly circular, entering into dorsal profile, its horizontal diameter 4.3 in length of head. Iris round. Horizontal diameter of orbit greater than vertical. A notch along lower edge of orbit. Width

TABLE 1.—COUNTS AND PROPORTIONAL MEASUREMENTS (IN PERCENT OF STANDARD LENGTH) TAKEN FROM THE TYPE OF AULOPUS NANAE AND COMPARATIVE EASTERN ATLANTIC SPECIMENS OF A. FILAMENTOSUS AND A. CADENATI

	Aulopus nanae; holotype; USNM 158985; male; Gulf of Mexico	*Aulopus filamentosus;* male; Madeira	*Aulopus filamentosus;* female; Madeira	*Aulopus filamentosus;* male; Azores	*Aulopus cadenati,* paratype R. G. Mus. Congo 95184; female; tropical West Africa	*Aulopus cadenati,* paratype R. G. Mus. Congo 95182–3; male; tropical West Africa
Counts:						
Dorsal fin	15½	16½	15½	15½	14½	14½
Anal fin	12½	12½	11½	11½	11½	12½
Pectoral fin	12/13	13/13	12/13	12/13	13/14	13/13
Ventral fin	9/9	9/9	9/9	9/9	9/9	9/9
Caudal fin	I–17–I	I–17–I	I–17–I	I–17–I	I–17–I	I–17–I
Branchiostegal rays	15/16	16/16	16/16	16/16	15/16	16/16
Gill rakers (first arch)	3+1+10	2+1+11	3+1+10	3+1+10	2+1+10	3+1+9
Vertebrae	47+1	51+1	50+1	50+1	49+1	49+1
Scales in lateral line	48	52	52	52	50	51
Predorsal scales	12	15	15	16	13	13
Measurements:						
Standard length (mm)	223.0	292.0	278.0	217.0	197.0	227.5
Depth at origin of dorsal fin	16.6	18.3	15.5	15.9	16.5	17.9
Depth at origin of anal fin	11.7	11.8	11.3	10.4	11.2	11.8
Depth at origin of adipose fin	9.4	9.9	9.9	9.4	9.8	9.7
Least depth of caudal peduncle	6.6	7.0	6.5	6.9	6.4	6.1
Width of body at pectoral fin base	15.0	14.6	14.9	—	15.8	16.6
Length of head (greatest)	30.0	31.5	30.4	30.4	31.5	32.4
Snout to uppermost point of gill opening	20.6	22.6	22.4	20.6	22.9	22.9
Length of snout	8.3	9.2	9.0	7.8	9.9	9.0
Horisontal diameter of eye	6.9	6.5	6.6	7.4	8.1	8.6
Vertical diameter of eye	6.3	5.3	5.7	6.0	6.5	6.6
Postorbital length of head	15.8	16.3	16.0	15.7	15.9	16.8
Posterior edge of eye to uppermost point of gill opening	5.6	7.2	7.2	6.5	6.0	6.5
Width of bony interorbital	3.6	4.8	4.3	4.1	3.8	4.1
Length of premaxillary	14.6	16.1	15.8	15.7	15.3	15.3
Snout to origin of dorsal fin	36.4	37.7	37.2	36.9	37.6	38.5
Snout to origin of anal fin	68.8	72.8	73.5	73.3	73.9	74.1
Snout to origin of pectoral fin	29.6	31.7	31.5	30.6	32.0	32.5
Snout to origin of ventral fin	34.9	38.7	38.5	36.6	38.1	37.8
Origin of dorsal fin to origin of anal fin	38.3	38.0	37.8	40.4	38.9	39.8
Origin of ventral fin to origin of anal fin	35.6	36.2	36.0	35.9	37.4	36.3
End of base of dorsal fin to origin of anal fin	18.8	19.0	19.2	20.3	20.1	20.2
Anus to origin of anal fin	10.5	9.4	10.1	10.1	10.1	10.8
Length of base of dorsal fin	21.7	21.4	21.1	21.0	20.0	20.2
Length of base of anal fin	13.9	12 5	11.3	11.1	11.5	11.4
Origin of dorsal fin to tip of longest ray (fin depressed)	—	40.4	29.6	33.2	27.4	30.3
Origin of anal fin to tip of longest ray (fin depressed)	29.1	21.1	16.7	19.1	18.0	19.6
Length of second dorsal ray	—	39.4	16.5	28.8	16.2	19.8
Length of penultimate dorsal ray	18.6	15.9	9.9	14.7	9.4	11.9
Length of second anal ray	12.8	11.0	8.6	10.6	8.4	10.3
Length of penultimate anal ray	16.6	9.7	6.5	9.0	6.5	7.9
Length of last anal ray	15.2	9.6	5.8	7.6	6.5	7.7
Length of pectoral fin	—	16.3	14.7	16.6	16.4	16.0
Length of ventral fin	27.6	24.6	19.6	25.6	20.3	20.2

of fleshy interorbital slightly greater than vertical diameter of eye. Width of bony interorbital 1.9 in horizontal diameter of eye. Opercular flap long and thin, extending posteriorly below and beyond origin of pectoral fin, the posterior edge formed by the subopercle.

Maxillary extending to below posterior fourth of eye, its length 2.1 in length of head, expanded posteriorly, and bearing two supramaxillaries, the larger of which overlies the posterior half of the maxillary. Angle of gape below center of eye. Anterior and lateral surfaces of lower jaw rugose.

Teeth on mandible, tongue and premaxillary, vomer, and palatine bones. Symphysis of lower jaw edentulous. Rami with a broad band of pointed, conical teeth which are straight or

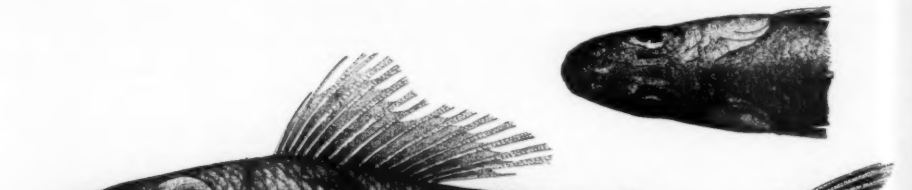

FIGURE 1.—*Aulopus nanae*, holotype, U.S.N.M. 158985. (Drawn by Nancy W. Mead.)

slightly recurved. The inner teeth of this band are longer than the outer, and are depressible. Most of the larger outer mandibular teeth are depressible; the smaller are fixed. A broad longitudinal band of minute teeth on tongue. Teeth on premaxillary in a broad band similar to those on the mandible; the inner largest, conical and pointed, slightly recurved and depressible; the center smaller with some larger depressible teeth and a greater number of smaller fixed teeth. A patch of depressible teeth of various sizes on the vomer, the series continuous across roof of mouth anteriorly. Two rows of conical teeth on each palatine, the inner teeth longer and more easily depressible than the outer. (The palatine teeth in larger comparative specimens of *A. filamentosus* from Madeira are in a broad band, those on a fish of intermediate size from the Azores are intermediate between a band and two parallel rows. These rows probably fuse to form a band with growth.)

Gill rakers present on first and second arches. Those on first arch bear spines along the inner side and at the tip; those on the second are covered with spines throughout, and on the third and fourth arches patches of spines on the arches themselves replace the gill rakers. Those on the first arch are of moderate length; that at the angle of the arch is about the same length as the opposing gill filament.

Distance from snout to insertion of pectoral fin 3.4 in standard length, the fin short, extending to beneath the base of the seventh dorsal ray. The upper two pectoral rays simple, the remainder branched. Distance from snout to origin of ventral fin 2.9 in standard length and about equal to predorsal length. Ventral fin long, 1.1 in length of head, extending beyond anus. The first and last rays are simple, the rest branched. The ends of the anterior four rays are thickened. Snout to origin of dorsal fin 2.8 in standard length, the fin long and high. (The anterior rays, which are filamentous in male *A. filamentosus* but not greatly produced in *A. cadenati*, may be broken in this specimen.) Length of penultimate dorsal ray 1.2 in length of base of dorsal. Anterior two dorsal rays simple. Adipose fin inserted over sixth anal ray, its length equal to width of base of ventral fin. Snout to origin of anal fin 1.5 in standard length; length of base of anal fin 2.2 in length of head. Height of fin (insertion to tip, fin depressed) almost equal to length of head. Length of penultimate anal ray much greater than depth of body at origin of anal fin, 1.8 in length of head. Distance from end of base of dorsal fin to origin of anal fin 5.3 in standard length. Anus to insertion of anal fin 2.8 in length of head.

Color in alcohol: Head purple, body yellowish with purple blotches of irregular size and not bilaterally symmetrical. Pectoral and anal fins colorless. Ventral fins, especially the thickened tips of the anterior rays, reddish. Tips of anterior four dorsal rays black, the rest of the fin dusky. Caudal fin dusky with a darker spot on the middle of each lobe.

NOMENCLATORIAL NOTE ON AULOPUS FILAMENTOSUS

Under the name of "der Borstenlachs," Bloch (1792: 424, pl. 9) described and illustrated a fish specimen from Livorno, Italy. No scientific name

was given for this species, which he recognized as new. C. S. Rafinesque-Schmaltz (1810: 56) described but did not figure a new Mediterranean species, *Salmo tirus*. This fish, probably identical with Bloch's "Borstenlachs", has been considered a synonym of *Aulopus filamentosus* since that name combination was first proposed in 1816.

This name combination appeared twice in the French dictionaries of 1816. Both entries were based on a Cuvier manuscript. Bosc (1816: 78) proposed *Aulopus* as a subgenus of *Salmo*; his entry was not accompanied by a diagnosis or description. Cloquet (1816, suppl. p. 128) accorded *Aulopus* full generic status and published a short diagnosis of *A. filamentosus*. Cuvier's description followed a year later (1817: 170).

It now seems likely that there are several species of *Aulopus* in the eastern Atlantic. In the absence of adequate series of eastern Atlantic and Mediterranean specimens, it is impossible to determine whether or not Rafinesque's poorly described *Salmo tirus* is identical with the *Aulopus filamentosus* of Cuvier or the "Borstenlachs" of Bloch. *Aulopus filamentosus* is used here for the eastern Atlantic form typified by Cuvier's description and Bloch's figure in preference to Rafinesque's earlier but at present dubious species. The trivial name should be credited to Bosc or Cloquet, not to Bloch (a common practice) or to Cuvier (prevalent in the Italian literature).

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The most beautiful thing we can experience is the mysterious. It is the source of all true science and art.—EINSTEIN.

ICHTHYOLOGY:—Garmannia zebrella, *a new gobiid fish from Trinidad, with notes on the species of the subgenus* Tigrigobius *Fowler.*[1]

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(Received March 24, 1958)

Recently the writer and James E. Böhlke compared some gobiid fishes from Florida, the Bahamas, and other stations in the Gulf and Caribbean. It was apparent that the name *Garmannia macrodon* (Beebe and Tee-Van) had been applied to two distinct but closely related species, the second of which is described below as new.

Apart from the original descriptions little additional information has been forthcoming on *Garmannia macrodon* and *G. pallens* Ginsburg. Recent collections in the Florida Keys enable the writer to provide descriptive and behavioral notes on *macrodon*.

For the loan of material and for helpful information and many kindnesses received at their respective institutions I am indebted to James E. Böhlke of the Academy of Natural Sciencies of Philadelphia and Leonard P. Schultz of the United States National Museum. Giles W. Mead, Ernest A. Lachner, and Robert H. Kanazawa have aided me in many ways during my visits to the National Museum. I am especially indebted to Isaac Ginsburg for advice and for providing unpublished data on *G. pallens*.

This study represents a portion of the work supported by the National Science Foundation (NSF-G-3881) and constitutes a technical report to that organization. The writer gratefully acknowledges this assistance.

Garmannia zebrella, n. sp.

Fig. 1, Tables 1–2

?*Gobiosoma multifasciatum*, Metzelaar, 1919: 139 (misidentification; for account of this record see Ginsburg, 1933: 55). ?Koumans, 1931: 53 (apparently based on Metzelaar's material).

Gobiosoma macrodon, Fowler, 1931: 401 (misidentification; characters in part, incorrectly described). Ginsburg, 1933: 53 (in part: Curaçao records probably referable to *zebrella*).

Material examined.—The holotype, ANSP 53387 (standard length, 21.0 mm) and two paratypes, ANSP 53388 and ANSP 53389 (standard lengths 16.1 and 15.5, respectively) were collected at Monos Island, Trinidad, on June 27, 1950, by L. Wehekind.

Diagnosis.—In preservative, a straw-colored goby with 13 prominent and sharply defined dark brown bands on the body behind the pectoral fin. Six additional bands in front of the pectoral fin. Body naked with a few modified ctenoid scales at the caudal base and on the posterior portion of the body. Spinous dorsal of seven elements, the first filamentous. Distance between spines 5 and 6 and 6 and 7 much greater than between any of the first five spines. Dark bands fairly broad, subequal to the light-colored interspaces. Two large and very prominent canines in anterior portion of inner row of teeth on the lower jaw.

Description.—Thirteen dark brown bands cross the body behind the pectoral fin. They are arranged as follows: the first crosses the dorsum in front of the insertion of the dorsal fin but not in contact with it. This band slopes slightly caudad to pass immediately behind the insertion of the pectoral fin. It is not continued across the midline of the belly but a faint suggestion is present on each side of the base of the pelvic disc at a point opposite the lower end of the band. The next three bands pass through the base of the spinous dorsal and each is represented by an adjacent dark squarish mark in the fin membrane. These three bands, as well as all posterior ones, become thinner and somewhat less distinct on the venter. The first of group of three bands does not cross the midventral line but the others do although the midventral portion is poorly defined. Five bands pass around the body through the base of the second dorsal fin in a manner similar to those under the first dorsal. A square blotch, fused to the band, extends for some distance upward in the fin membrane. The first of these five bands circles the belly just behind the genital papilla and in advance of the anal-fin insertion. Three of the remaining four circle the belly under the anal-fin base and the fourth passes just caudad

[1] Contribution No. 197 of the Marine Laboratory, University of Miami.

TABLE 1.—FREQUENCY DISTRIBUTIONS OF FIN-RAY COUNTS IN *GARMANNIA MACRODON* AND *GARMANNIA ZEBRELLA*

Species	Dorsal spines		Dorsal rays		Anal rays			Pectoral rays				Caudal rays	
	VI	VII	11	12	9	10	11	16	17	18	19	16	17
G. macrodon	1	41*	34*	8	3	36*	3	4	69*	11	—	4	37
G. zebrella	—	3	2	1	—	3	—	—	—	4	2	—	3

TABLE 2.—FREQUENCY DISTRIBUTIONS OF BODY PROPORTIONS EXPRESSED IN HUNDREDTHS OF STANDARD LENGTH

Species and size range in millimeters	Head length									Eye diameter					
	26	27	28	29	30	31	32	33	34	5	6	7	8	9	10
G. macrodon:															
>30	1	—	—	1	—	—	—	—	—	1	1	—	—	—	—
25–29	—	1	5	4	3	2	—	—	—	—	5	8	1	—	—
20–24	—	—	2	1	3	3	—	—	—	—	—	3	4	1	—
<20	—	1	2	1	6	3	1	1	1	—	—	1	6	7	3
G. zebrella:															
16–21	—	—	—	—	2	1	—	—	—	—	—	—	2	1	—

	Prevent										Depth at vent				
	54	55	56	57	58	59	60	61	62	63	18	19	20	21	22
G. macrodon:															
>30	—	—	1	1	—	—	—	—	—	—	—	—	—	—	2
25–29	—	1	3	6	—	3	1	—	—	2	—	2	3	5	4
20–24	—	—	—	2	2	3	1	—	—	—	—	1	2	4	2
<20	1	—	—	2	2	3	5	—	—	1	1	1	3	5	5
G. zebrella:															
16–21	—	—	—	—	1	—	—	2	—	—	—	—	—	2	1

	Length of pectoral fin										Depth at nape				
	25	26	27	28	29	30	31	32	33	34	20	21	22	23	24
G. macrodon:															
>30	—	2	—	—	—	—	—	—	—	—	1	—	1	—	—
25–29	2	2	2	3	1	3	—	—	—	—	2	2	9	1	—
20–24	—	2	2	—	2	1	—	—	—	1	—	2	4	2	—
<20	—	—	—	1	1	2	4	1	2	—	4	5	5	2	1
G. zebrella:															
16–21	1	—	—	—	—	1	—	—	—	1	—	2	1	—	—

	Predorsal length									Length of pelvic fin									
	31	32	33	34	35	36	37	38	39	19	20	21	22	23	24	25	26	27	28
G. macrodon:																			
>30	—	1	—	1	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—
25–29	1	—	1	1	5	4	2	—	—	1	5	4	3	—	—	1	—	—	—
20–24	—	—	1	2	1	3	1	1	—	—	—	2	3	1	2	—	—	—	—
<20	—	—	—	3	3	3	3	3	1	—	1	2	2	3	3	3	1	—	1
G. zebrella:																			
16–21	—	—	—	2	—	—	1	—	—	—	—	—	1	—	1	—	1	—	—

of the insertion of the last anal ray. All are well defined ventrally. Two bands circle the caudal peduncle and do not contact any fin. The twelfth of the thirteen bands on the body behind the pectoral fin circles the body through several anterior procurrent caudal rays. The final band is incomplete on the dorsal and ventral surfaces and extends as a vertical bar external to the posterior edge of the hypural plate and thus near the bases of the main caudal rays.

Six bands are present in advance of the pectoral fin making 19 bands in all on the fish. The first, a single medium band, extends from the tip of the snout across the upper lip (not visible on Fig. 1). It continues after a slight gap on the lower lip and ends on the mid-gular region. The second band begins medial to and slightly behind the posterior nostril and continues downward and forward across the medial surface of the tubular anterior nostril, across the upper lip, and onto the lower lip. It is interrupted here but continues caudad across the branchiostegal membranes in somewhat irregular fashion. Band three is almost semicircular in outline; starting on the midline of the nape and then splitting to both sides, it extends onto the upper surface of the eye, continues downward across the anterior margin of the eye and then caudad across the posterior end of the maxillary where it ends. A slight mark on the lower cheek and another on the branchiostegal membranes represent its continuation. The band actually splits on the upper edge of the eye to form a small open circle but owing to the dark pigment of the eye this is not easily seen. Bands four and five cross the back in semicircular fashion, the open side of the bow being forward. Band four extends forward and ventral across the posterior edge of the eye where it may be interrupted, and then crosses the cheek. Band five is much broader than bands one to four and nearly as broad as those on the body. It crosses the side of the head behind the eye and terminates on the lower edge of the interopercle. The last of the bands anterior to the pectoral fin crosses the dorsum as a straight line and extends downward through the opercular membrane to end at the insertion of the lowermost pectoral ray.

The width of the dark bands is diagnostic for the species, the dark areas being only slightly narrower than the intervening pale area. The combined width of the 2 dark bands far exceeds the width of the intervening light-colored one.

All fin membranes are liberally covered with melanophores. Frequency distributions of fin-ray counts and of morphometric data are given in Tables 1 and 2. All three specimens possess seven dorsal spines. Spines 1 to 5 are evenly spaced and the first is filamentous. The space between spines 5 and 6 is twice that between any of the preceding rays and spine 7 is only a little less distant from spine 6, the gap being about one and one-half times that between any of the first five spines. There are 11 or 12 dorsal and 10 anal rays. Total caudal elements number 28 or 29 (procurrent elements included). Of them, 17 are cross striated in all three specimens. There are 18 or 19 pectoral rays. Each pelvic fin consists of one spine and five rays, the two fins joined to form the typical gobiid disc. The disc is free from the body. A frenum is well developed and heavy, firmly uniting the two pelvic spines and forming a pocket across the anterior end of the disc. The anal fin is inserted under the third dorsal ray.

The body is nearly scaleless. Four modified ctenoid scales are evenly spaced at the base of the caudal fin and a patch of from 9 to 12 ctenoid scales are present on the sides of the caudal peduncle between the tenth and twelfth dark bands.

A broad patch of depressible teeth is present on the dentary. The outer row is directed slightly forward and its teeth are somewhat larger and flatter than those of the other rows. The dentary patch is broad across the region of the symphysis but tapers rapidly along the sides of the jaw. About midway along these projections are two large recurved fangs, one on the inner and outer edge of each process. The premaxillary teeth are similar but the patch is not so broad anteriorly as that of the dentary. Its outer row is similarly enlarged and directed forward. The tooth patch narrows considerably but reaches the end of the maxillary process of the premaxillary. At its tip are one or two fangs, not so large as those in the lower jaw but nonetheless conspicuous.

The gill opening is restricted; its origin is opposite the second pectoral ray, its lower extreme just below and forward of the last pectoral ray. There are 8 gill rakers on the holotype, one on the upper and seven on the lower limb.

Range.—*G. zebrella* is known only from the type locality, Monos Island, Trinidad.

Name.—The diminutive of *zebra* in reference to the banded color pattern.

Garmannia macrodon (Beebe and Tee-Van)

Fig. 1, Tables 1–2

Gobiosoma macrodon Beebe and Tee-Van, 1928: 226 (figure, description).

Garmannia macrodon, Ginsburg, 1933: 53–55 (Synonymy in part, characters, relationships). Ginsburg, 1939: 63 (related to *Garmannia pallens*). Fowler, 1941: 96 (recorded from Sanibel Island, southwest coast of Florida). Ginsburg, 1944: 379 (placed in subgenus *Tigrigobius* of *Garmannia*).

G. macrodon is described in some detail by Ginsburg (1933: 53–55) and only a few features need be discussed here. Fin-ray counts and morphometric data are presented in Tables 1 and 2. Since some body proportions vary with specimen size, these data are arranged by size classes. Of 41 specimens examined 37 had 17 cross-striated caudal rays and 4 had 16. The bands on the body are arranged precisely as that described for *zebrella*. The dark bands are narrow, their width being less than one-third of the pale interspace. The second band behind the eye is bowed on the dorsal surface of the head. In life the dark bands have a maroon cast and at least during the winter months the elongate first dorsal spine is yellowish.

The gill opening is restricted, its width only slightly exceeds the width of the pectoral base. The gill rakers are short and stubby and usually number 1 + 7, the uppermost on the lower limb being near the angle. Counts for five specimens are: 1 + 7(3), 1 + 8(1), 2 + 7(1).

A black streak extends along the dorsal-fin membrane about one-third of the distance from the base to the fin edge. The distal two-thirds of the caudal fin and the entire pelvic disc are largely dark. The anal fin is dark except for narrow basal and distal stripes. Four ctenoid scales are present at the caudal base in all in-

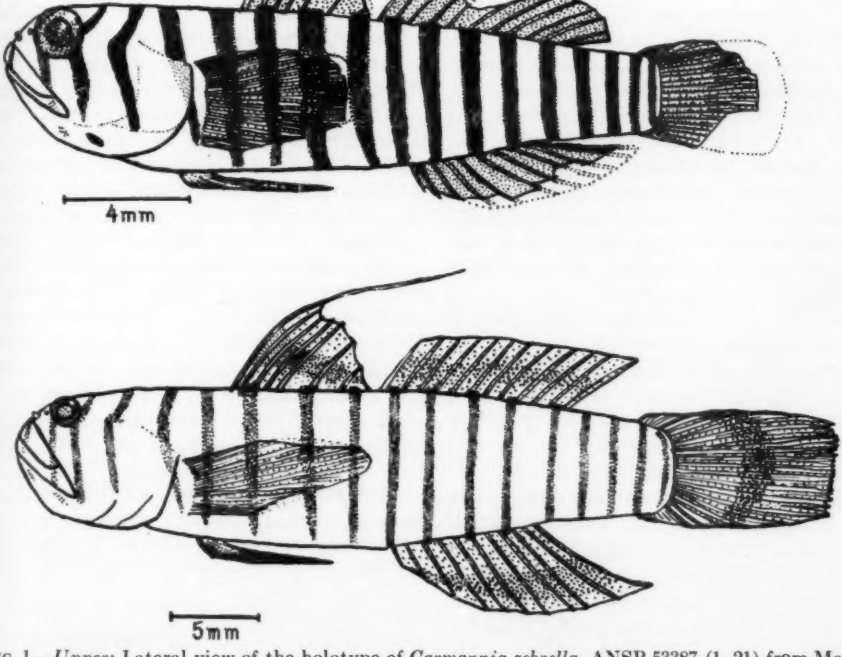

FIG. 1.—*Upper:* Lateral view of the holotype of *Garmannia zebrella*, ANSP 53387 (1, 21) from Monos Island, Trinidad. *Lower:* Lateral view of an adult *Garmannia macrodon*, UMML 873 (1, 37) from Dinner Key at Miami, Fla. (The figures are to show the diagnostic color patterns and general body form. The fine structure of the fins are generalized and such details as the scales on the caudal peduncle are omitted.)

dividuals examined but the remainder of the squamation varies. Usually there are four or five scales on the posterior portion of the caudal peduncle, most below the midline.

During January 1957 this species was observed in the Florida Keys on the bay side of Crawl Key where a deep quarry nearly a quarter mile across and more than 50 feet deep had been dug years before. The quarry is broadly connected over a shallow sill to the ocean. It has stabilized and supports a rich tropical fish fauna. In the winter little algal growth occurs on the rock sides and silted rubble bottom. At this time two gobiid fishes, *Coryphopterus glaucofrenum* Gill and *Garmannia macrodon* abounded. The bridled goby, *C. glaucofrenum* is found on the terraces from 5 to 20 feet below the surface, always lying near a hole or the side of a rock into or under which it can retreat. *G. macrodon* perches on top of the rocks in the same depth range, swimming along their surfaces in the manner characteristic of the neon gobies (*Elecatinus*). Despite their prominent bands they are difficult to perceive. No collections were made at this time.

When the same area was revisited on October 12, 1957, by Raymond B. Manning and myself, *C. glaucofrenum* was still in its usual haunts but no *Garmannia* could be found after extended survey. A third goby, *Barbulifer ceuthoecus* (Jordan and Gilbert) was observed at Crawl Key on this occasion, usually in water less than one foot deep. Here on well silted rubble bottom it occurs under the rocks and is never numerous. It avoids the vertical walls and at least in our experience does not ecologically overlap either *Coryphopterus* or *Garmannia*.

The vertical rock ledges were covered by a dense net of algae, pale reddish but somewhat variegated in color. A cloud of rotenone was released along this algal mat from the surface to 15 feet. Every few feet along the poisoned wall, between a depth range of 5 and 15 feet *Garmannia* emerged, usually in pairs, one large and one small individual. In general these proved to be males and females; the latter apparently rarely exceed 20–22 millimeters in standard length. None were found away from the algae or even on the non-vertical portions of the rock wall. No nests or eggs could be found in the loose mat which was extensively tunneled. *G. macrodon* seemed very disturbed when placed away from the wall. They swam in circles and were unable to return even when only a yard or two from the wall. When taken out over deep water (down a few feet from the surface) they completely lost their orientation and swam in tight gyrals. Often they were upside down. This erratic behavior ceased when we placed a hand to the goby. Immediately it regained its orientation and swam over and under it always with its ventral surface closely appressed to the surface. Thus it would be upside down on the lower side just as it moves along its more normal rock and algal haunts. Apparently *macrodon* depends completely on contact with the substrate and loses orientation when such is not available.

A specimen from off Dinner Key at Miami, Fla. (UMML 873) was supposedly taken from a fire sponge (*Tedania*). This may have been an unusual circumstance for the species has not been noted among the material collected from sponges in our field program.

The holotype recorded by Beebe and Tee-Van (1928: 226) as no. 7462 in the Tropical Research Collection of the New York Zoological Society is now at the United States National Museum (USNM 170896).

Range.—*G. macrodon* is known from Sanibel Island (Fowler, 1941: 96) on the southwest coast of peninsular Florida and Dinner Key at Miami on the southeast coast southward through the Florida Keys. Elsewhere it is recorded from Port-au-Prince Bay, Haiti (Beebe and Tee-Van, 1928: 226–227). Its supposed occurrence in Curaçao needs verification for Metzelaar's (1918: 139) record would seem applicable to *zebrella*.

Material examined.—Haiti: USNM 170896 (1, 29) HOLOTYPE. Florida: UMML 873 (1, 37), Dinner Key, Miami; UMML 1612 (99, 16–31) ANSP 79168 (10, 20–28), Crawl Key, Florida Keys; USNM 73094 (2, 18), USNM 73096 (1, 21), USNM 57410 (1, 29), USNM 73095 (1, 25), USNM 93745 (2, 16–19), USNM 73093 (1, 20), USNM 118168 (2, 14–17) all from various localities in the Florida Keys.

Garmannia (Tigrigobius) pallens Ginsburg

Garmannia pallens Ginsburg, 1939: 63 (original description). Ginsburg, 1944: 379 (placed in subgenus *Tigrigobius*, compared with *macrodon*).

Ginsburg's (1939: 63) brief account of *G. pallens* anticipated a fuller description in a later monograph which unfortunately has never been published. Reexamination of the holotype, USNM 107327 (1, 12) reveals a badly faded specimen in rather poor condition. Only ten

bands are still discernible behind the pectoral base. The band immediately behind the eye is semicircular in outline but the next is nearly straight. The anterior nostril is tubular. The following diagnosis, from Mr. Ginsburg's unpublished files may facilitate its identification.

Diagnosis.—Anterior part of body naked; posterior part scaled, the scales imbricated; scales extending forward to under bases of sixth to eighth dorsal rays, in about 9–12 oblique rows; anterior bare areas above and below tapering to a little behind base of dorsal and anal; 4 scales in row on caudal (scales partly missing and above statements subject to correction). First spine of male prolonged, reaching to base of fourth ray, not prolonged in female. Dorsal rays 11; anal rays 9 (same count in 2 specimens); pectoral rays 15 or 16. Head well compressed. Maxillary reaching slightly past posterior margin of eye in male, to under posterior margin of pupil in female.

Ground color light yellowish, crossed by narrow dark bands, narrower than the interspaces, the bands rather faint as compared with *macrodon*; 13–14 bands from base of pectoral to that of caudal, 3 or 4 of the bands in scattered positions confined to a short distance at the dorsal profile; 3 bands on head behind eyes confined to dorsal aspect; bands on head and anterior part of body fainter than posterior ones; in female bands in general still fainter than those in male, those on head and anterior part of body nearly obsolescent; a very fine, faint, somewhat interrupted, longitudinal, median streak on posterior part of body; male with a dark somewhat elongate spot under eye, near its posterior margin, and a more diffuse dark streak running obliquely from directly under middle of eye to posterior end of maxillary.

Discussion.—The three species currently assigned to *Tigrigobius* form a closely knit group. When the structure and relationships of gobiid genera are better known, the three may be treated as a species group in a more inclusive subgenus. The type species of *Tigrigobius* needs clarification. Fowler's (1931: 401) *Gobiosoma macrodon* is *Garmannia zebrella* and no material of *macrodon* was in the collection at the Academy of Natural Sciences of Philadelphia at the time of that paper. Thus the subgenus *Tigrigobius* is based on specimens of *zebrella* (the holotype and paratypes listed above) which were erroneously identified with *macrodon*. Since the two species are clearly to be placed together in any generic or subgeneric alignment the problem is purely a technical one. My interpretation of the current rules of nomenclature leads me to consider *Garmannia macrodon* (Beebe and Tee-Van) as the type species.

The banding is best developed in *zebrella*, thinner in *macroden* and somewhat reduced in *pallens*. The dark bands are wider than one-half of the light colored interspace in *zebrella* and less than one-third of the interspace in *macrodon*. *G. pallens* differs in having the second band behind the eye forming a straight line across the occiput while it is bowed in *zebrella* and *macrodon*. *G. zebrella* differs at least from *macrodon* in having the bar on the cheek remote from the end of the jaw instead of bordering it (see Fig. 1). This feature could not be determined for the faded holotype of *pallens*. The pectoral rays vary from 18 and 19 in *zebrella* to 16–18 in *macrodon* and 15–16 in *pallens*. The scalation is best developed in *pallens*, somewhat reduced in *zebrella*, while only a few scales are present in *macrodon*. The characters thus do not form a gradient. Specimens from intermediate areas are required to more fully evaluate the specific status of the three forms. Material of *pallens* is especially wanting.

Metzelaar (1919: 139) and Koumans (1931: 53) confused *zebrella*(?) with *Gobiosoma multifasciatum* and Fowler (1931: 401) related *macrodon* (=*zebrella*) to *Gobiosoma viridistriatum* (a synonym of *multifasciatum*—see Ginsburg 1933: 27). Despite this, the species of *Tigrigobius* bear no direct relation to the banded species of *Gobiosoma*. Its relations lie with *Garmannia* as discussed by Ginsburg (1933: 54). In addition to basic differences in squamation, etc. discussed by Ginsburg, *Gobiosoma multifasciatum* does not closely resemble the species of *Tigrigobius* in its pigmentation. A specimen of *multifasciatum*, USNM 117415 (1, 20) was examined and the following notes recorded. Superficially it differs from *macrodon* and its two allies in being dark colored with very discrete narrow pale bands and in having a circular dark humeral spot, which is separated from a large wedge-shaped mark by a pale band. The spot is only slightly smaller than the eye and the wedgeshaped mark (reddish in life?) begins above the gill slit and stops just short of the eye. The dark bars on the body have a narrow black border and the pelvic disc is much shorter (2.7 mm in this specimen). Fin-ray counts were: dorsal, VII,12; anal, 10; pectoral 20-20.

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RIVER BASIN SURVEYS UNEARTH BIG PLAINS INDIAN TOWN

Remains of what probably was the biggest "town" of the Plains Indians in the Missouri Basin have been uncovered by Smithsonian Institution archeologists working in the area to be flooded by the large Oaho Dam. At the time of occupation the village consisted of earth lodges, customary habitations of the sedentary northern Plains tribes, and accessory buildings which covered an area of 4,000 by 1,500 feet. Indications are that there were some 400 dwellings and 4 large ceremonial lodges located there.

This large community, which must have had several thousand inhabitants, was located on the left bank of the Missouri River some 20 miles above Pierre, S. Dak., according to a River Basin Surveys report. It was noted and recorded during earlier preliminary reconnaissance by a group from the Missouri Basin Project of the River Basin Surveys. During the summer of 1956 testing operations were carried out by a party under the direction of Dr. Robert L. Stephenson. At that time a detailed map was made of the area and the site was staked off into 100-foot blocks. A 5-foot square test hole was excavated at each 100-foot stake along the sides of the site. In addition two trenches were dug and a house quadrant excavated. The testing was for the purpose of determining where a maximum of information could be obtained from a minimum of digging.

Dr. Stephenson returned to the site with a larger party in the summer of 1957 and with the work of 1956 as a guide began a series of excavations. This party uncovered the remains of 13 circular earth lodges and one and one-half of the four large ceremonial lodges. The house pits ranged from 25 to 60 feet in diameter and were 2 to 4 feet deep. Entrances were to the southwest, generally, and two distinct architectural patterns were observed. One was composed of closely set double rows of small, outer-wall posts. The other was composed of widely spaced single rows of outer posts with leaner posts outside of them. This suggests two closely related occupational patterns and the artifacts recovered support such a differentiation. There were certain indications that there had been an earlier occupation featuring rectangular houses, but no such structures were found in the areas excavated. Cache pits were abundant and were found to range from small holes to large bell-shaped pits 7 feet in diameter and 7 feet deep. Artifacts were abundant in the fill in such pits and an outstanding specimen, a red-stone plaque with figures of buffalos engraved on each side, came from one of them. Included in the collection are stone and bone tools, stone knives and arrowheads, several catlinite pipes, several ornaments made from marine shells, an ornament of turquoise, and different kinds of potsherds.

Skeletal materials for study by physical anthropologists were also recovered. The major occupation at the site appears to have been by the Arikara or their immediate ancestors during the period 1600 to 1750 and since little is known about the physical type of the people the skeletal material will help to fill that gap in the knowledge of the Indians of that period.

AUTOMATIC SORTING MACHINE FOR LETTER MAIL

A laboratory prototype machine for the automatic, high-speed sorting of letter mail has been developed by the Rabinow Engineering Co. under a contract arranged and supervised by the National Bureau of Standards for the Post Office Department. The machine is designed to sort at the rate of 36,000 letters per hour into as many categories as may be needed. Sorting can be directed either by a built-in electronic control, by human operators, or by a combination of both. The system is of modular design and thus adaptable to the varying needs of different post offices, with regard to both sorting complexity and spatial requirements. The machine has proved successful in laboratory tests, and the Post Office Department has recently let a contract for the construction of a 1000-pocket production prototype to be used in a post office.

For some time the Post Office Department has been seeking mechanized sorting methods to assist its personnel in keeping up with the continuing rapid growth of letter mail. Because of its specialized experience with data processing machines and electronic equipment, the National Bureau of Standards has been aiding the Post Office on various mechanization problems. NBS has been developing methods and machines to speed the handling of mail. Much of the equipment development and nearly all construction have been placed in the hands of private industry.

Two basic problems are involved in mechanized letter sorting. One is concerned with the information content of the address and with the mechanics of the control that must be provided by some computer-like device for directing the mail sort. The other problem is concerned with the physical handling of the mail. Today's envelopes and their contents are obviously not designed for mass handling by machine. This fact complicated the design of the present machine. If eventually standardized envelopes and addresses could be made acceptable for wide scale use the task of the machines would be much easier and cost reduced.

Work on these problems at the Bureau has proceeded along several lines. Data have been and are being collected in representative cities to form an engineering basis for the system and machine design. These data include such items as the general nature of the mail, i.e., the size and shapes of envelopes, the percentage of hand-written vs. typewritten mail, and the range of color of envelopes; the number of letters handled each day and their distribution by times of day; and the nature of distribution of local mail and outgoing mail. Studies are under way on methods of converting the written or printed address into a code printed on the envelope either with visible or invisible inks, or with magnetic materials. Development of special phosphorescent inks for this use is also in process.

The sorting machine developed by the Rabinow Engineering Co. consists essentially of a large number of pockets on an endless conveyor and electromechanical equipment that controls the dropping of a letter from a pocket into a specific fixed receptacle. Accompanying each pocket on the conveyor is a steel rod carrying 12 Nylon wheels. Each wheel can be shifted laterally on the rod into one of two positions. Thus, there are 2^{12} or 4096 combinations of wheel positions. As the conveyor moves, each set of 12 wheels rolls over tracks designed so that when the correct destination is reached all of the wheels drop into depressions and the letter is released.

The mechanical sorting and coding of letter mail begins at the code printer. Here letters from a stack of "faced" mail, moved by a conveyor belt, are picked off one at a time and mechanically placed in a reading-and-coding position in front of an operator. He reads the addresses, abbreviates their important parts, and types these abbreviations on the back of the envelope by means of a special printer.

The print coding is in a binary form, requiring 6 bits for each alphanumeric character. For outgoing mail, the coding operator may merely abbreviate the city and the state. The choice depends on whether all the coding is to be done at the initial location or part of the coding at the final destination, and on whether the city to which the letter is addressed is or is not equipped with automatic machinery. In sorting for local distribution, the city need not be mentioned, and only the street number and street name will be coded. In any case, not more than 64 bits would be required for the entire abbreviated address.

The operator then chooses, by push-button operation, one of four possible destinations—local, outgoing, airmail, or miscellaneous—and sends the coded letter through its first sort. The mechanism actuated by the push button opens a

trap door and sets a directing vane so that the coded letter drops into the proper pre-sort when it is released from the code printer.

It is expected that only a few seconds will be required to code an average letter. This operation may ultimately become the only human one in the entire sorting process. The reading head of the code reader is physically located in the reader-feeder-inserter mechanism immediately preceding the point where the letter is dropped into the conveyor. The sorting system is organized so that when adequate automatic reading machines become available they can be incorporated into the sorter with a minimum of alteration.

An electronic directory (sometimes called memory or translator) receives the coded, abbreviated address from the code reader, "looks up" the sorting destination for each address, and controls the delivery of the letter to that destination receptacle. The electronic directory output drives the code wheel setter which sets each group of code wheels on the conveyor carts to the appropriate coded arrangement to drop each letter in its final sort receptacle. The entire sequence involved in looking up the destination and setting the wheels is accomplished in approximately one-tenth of a second.

The electronic directory is an electro-mechanical-optical device specially designed to meet the requirements of the sorting machine. It converts, according to a pre-arranged schedule, the information in the 64-bit code of the abbreviated address on the envelop into a 12-bit code corresponding to the receptacle where the letter is to be dropped by the conveyor. The directory consists of a stack of 64 thin plates of stainless steel, each approximately 1 foot square. Each plate has etched into it 40,000 small round holes, about $\frac{1}{50}$th of an inch in diameter, spaced on $\frac{1}{16}$-inch centers. The plates are so suspended that they can be moved by an electromagnet from left to right $\frac{1}{16}$th of an inch. The plates are initially covered with an opaque black ink that fills the holes completely. Some of the holes are punched out to provide the directory with its address conversion data. Each plate corresponds to a dot position of the binary address code. If the code contains the full 64 dot positions, and if, by convention, each plate moves to the right if the dot is present and remains stationary if the dot is absent, each address will cause the plates to move into a unique set of positions.

Behind this set of plates are located 12 phototubes, each of which sees an area of roughly 3 by 4 inches of the plate stack. These areas do not overlap. In front of the plates is a source of light that illuminates the whole area of the plate stack. Removing the ink from certain of the holes in each plate to permit the light to reach any desired combination of phototubes creates a function table which converts a 64-bit input into a 12-bit output. This 12-bit output is the control for setting the 12 wheels that accompany each letter in the conveyor.

Etching holes in the plates and then filling them with ink ensures an accurate position for each final hole so that any set of 64 corresponding holes in the stack will line up. The directory contains approximately 1.5 million bits and no trouble with mechanical alignment of the holes has been experienced so far. The plates can be moved easily in $\frac{1}{10}$th of a second, thus keeping up with the rate of the sorting conveyor. This type of optical directory can also be used as any general-purpose function table. A much larger number of holes per plate, larger plates, or several sets of plates in parallel could be used and many variations of the basic scheme are possible. The memory in its present form could handle a city of 100,000 to 200,000.

Each letter is inserted by the reader-feeder-inserter into a separate pocket on the conveyor. At the same time the code wheels for each pocket are set according to the output of the directory so that its letter will be deposited into the proper final sort receptacle. A code wheel resetter returns all code wheels to their "zero" position following the dropping of the letter into the receptacle. The empty pockets are then reloaded and their corresponding code wheels are set for another sort.

In a less complex version of the machine, letter sorting is controlled by human operators instead of the equipment which reads the dot code printed on the envelope. The operators sit beside the conveyor belt, and letters are delivered to them automatically. Each operator reads the address, decides which receptacle of the conveyor the letter is to go into and depresses a combination of keys. This operation sets the position of wheels accompanying the pocket into which the letter will be dropped. At no time does the operator touch the letter. Such a machine can sort mail at rates as fast as 1 per second for each operator. It is expected that the initial version of the machine will sort letters at the approximate

rate of 10 per second, thus requiring 10 to 12 operators.

The sorting conveyor can be built in small modules so that machines of various sizes can be constructed to suit the particular size of the post office or of the sorting system used. The conveyor can be assembled in many layers so as to best utilize the available space in a particular building. Because the letters are carried vertically, and their motion is perpendicular to their faces, the overall speed of the conveyor can be kept low. Gravity drops are employed both for placing the letters into the conveyor and for removing them from the conveyor into their final receptacles. Considerable effort was spent to design the machinery in such a way that the "facing" of the letters will be preserved, that is, that the addresses on the envelopes will still face in the same direction after being sorted. Thus, refacing will not be necessary for any subsequent processing.

Special provisions are being made to enable the conveyors to be stacked in various arrays so that the letters can transfer from one conveyor to another for multiple sorting. The Bureau is making studies to find systems of sorting mail which will be economical both in cost of machinery and in the effective employment of operating personnel. It is possible to sort letters by short conveyors and use several successive sorts, or to use long conveyors and fewer sorts, or combinations of short and long conveyors so that some mail is sorted only once while other mail is sorted more often, depending on the volume and statistical distribution. Many of the factors involved in system design are difficult to evaluate, for example, the repeated handling of envelopes not designed for machine use as compared to the cost of large machinery where the letter need be handled only once. Actual experience with these machines in a post office should help to settle such problems in the next few years.

COLOR RESPONSE OF THE HUMAN EYE

To further the development of color standards and measurement methods, the National Bureau of Standards has been participating in an international study of color vision. Purpose of the study sponsored by the International Commission on Illumination,[1] is to define the color response of the average human eye. Pertinent physical properties of color standards can be measured by strictly physical methods; however, to compute a valid numerical specification of a perceived color from the physical measurements requires a determination of the eye's color response, technically expressed as "color-mixture functions."

A recent Bureau experiment for this study provides an approximate method for measuring the pigmentation that affects color judgment. The experiment confirmed the belief that the amount of lens pigmentation increases as a person grows older, but it showed that macular pigmentation remains relatively constant with age.[2] Results of the experimental data evaluated by K. L. Kelly of the Bureau's colorimetry laboratory, are expected to be of value in determining the eye's color-mixture functions.

The pigmentation that affects color vision in the normal eye occurs only in the lens and macula. The macula is the so-called "yellow spot" in the center of the retina. The iris, which gives the eye its external color—for instance, brown, gray, blue—is opaque, and does not affect color judgment. It is well known that the lens becomes yellower as a person grows older, but no method has been available to estimate the amount of yellowing either in the lens or in the macula. By utilizing a pair of metameric gray plaques devised by W. C. Granville,[3] the NBS investigators were able to measure the pigmentation present in the eyes of 39 persons with normal color vision, ranging in age from 18 to 77 (see Table 1).

THE EXPERIMENT

One of the plaques, a "simplex" gray, was produced by a mixture of white and black pigments, and the other, a "complex" gray, by a mixture of yellow, green, purple, and white pigments. When a person of "average" color

[1] Frequently referred to as either the CIE or the Commission Internationale de l'Eclairage.

[2] For further technical details, see *Observer differences in color-mixture functions studied by means of a pair of metameric grays*, by KENNETH L. KELLY, Journ. Research NBS **60:** 97. 1958. RP 2825.

[3] *Metameric color and the macular pigment*, by W. C. GRANVILLE and D. B. JUDD, Journ. Opt. Soc. Amer. **39:** 632A. 1949.

TABLE 1.—OBSERVERS CLASSIFIED ACCORDING TO SEX, AGE, EYE AND HAIR COLOR; DESCRIPTION OF TEST PANELS; AND RECIPROCAL COLOR TEMPERATURES REQUIRED FOR RED-GREEN BALANCE

Observer	Sex and age	Eye color	Hair color	Color of simplex relative to complex		Reciprocal color temperature, mrd, of match point		
				10°	2°	10°	2°	Diff.
1	M55	blue	brown	red	green	204	91	113
2	M45	hazel	brown	red	green	238	103	135
3	F56	brown	brown	red	green	179	47	132
4	M27	hazel	d. brown	pink	pink	278	196	82
5	M44	blue	brown	red	green	196	84	112
6	F39	blue	d. brown	red	green	213	132	81
7	M51	d. brown	black	slightly pink	green	213	78	135
8	M41	blue	blond	pink	green	256	149	107
9	M38	blue	red	pink	green	200	110	90
10	M21	hazel	auburn	pink	green	238	84	154
11	F50	hazel	brown	pink	slightly pink	256	189	67
12	M39	blue	blond	pink	pink	250	179	71
13	M62	blue	brown	pink	green	172	118	54
14	M34	blue	brown	red	green	222	135	87
15	M46	blue	brown	pink	green	213	71	142
16	M29	d. brown	black	pink	green	263	182	81
17	M34	d. brown	black	pink	pink	286	213	73
18	M47	blue	brown	match	green	189	65	124
19	F44	brown	d. brown	pink	green	238	159	79
20	M42	brown	brown	pink	match	227	149	78
21	M48	brown	brown	pink	green	222	175	47
22	F37	d. brown	d. brown	lavender	green	227	127	100
23	F23	brown	brown	pink	pink	256	164	92
24	F19	brown	brown	lavender	lavender	270	208	62
25	F29	blue	brown	red	match	278	154	124
26	F25	hazel	l. brown	lavender	match	250	170	80
27	M53	blue	brown	match	green	95	−14	109
28	M52	brown	brown	match	green	170	2	168
29	F42	d. brown	d. brown	pink	slightly pink	256	175	81
30	M66	blue	brown	green	green	91	−40	131
31	M68	blue	brown	green	green	130	−28	158
32	M21	hazel	blond	red	green	233	110	123
33	M36	blue	blond	red	green	196	29	167
34	F18.5	hazel	brown	pink	pink	278	170	108
35	M28	green	blond	pink	pink	270	161	109
36	M38	brown	l. brown	pink	pink	263	192	71
37	M56	blue	brown	red	green	196	84	112
38	M31	d. brown	black	pink	pink	256	182	74
29	M77	blue	brown	green	green	−118	<−118	—
Averages	41.3					214	<114	>100

vision views these plaques in daylight from a near position, the simplex gray appears redder than the complex gray. The near position is one at which the plaques subtend a visual angle of 10°. When the observer steps back a few paces to a position from which the samples subtend a visual angle of 2°, the simplex gray then appears greener than the other.

This phenomenon occurs because the retinal image of the samples at the 10° position covers both the macula and a large portion of the surrounding retina, while at the 2° position the retinal image falls wholly within the eye's macular pigment, which is yellow. The effect is somewhat analogous to placing a yellow filter in front of the eye for the 10° position, thus

reducing the color temperature of the light source, that is, making it redder. Consequently, the 10°-field results depend primarily on the lens pigmentation and the 2°-field results depend not only on the lens but to a large extent on the macular pigmentation.

In the Bureau's experiment, each observer viewed the two samples side by side at the 10° position. The color temperature of the light source was then reduced until neither sample appeared redder or greener than the other. This point was called the cross-over point, and was recorded as the reciprocal color temperature in micro-reciprocal degrees (μrd) of the source. The test was repeated at the 2° position. The reciprocal color temperature at each position was then plotted against age of the observer.

RESULTS

The observers were classified into five groups: (1) red-red; (2) red-match; (3) red-green; (4) match-green; and (5) green-green. The youngest observers, considered to have the least lens pigmentation, described the simplex gray as redder than the complex gray at both the 10° and the 2° positions. These observers were put into group 1. Those in group 2, with a little more pigmentation, said the simplex appeared redder at the 10° position but that it matched the complex at the 2° position. Group 3, which included most of the observers, described the simplex as redder at the 10° position and greener at the 2° position than the complex gray. Group 4, with still more lens pigmentation, said the simplex matched the complex at the 10° position but that it was greener than the complex at the 2° position. Several of the observers, including the older ones, were considered to have the most pigmentation because they saw the simplex greener at both positions. They were put in group 5.

The reciprocal color temperature of the source required to produce a red-green balance between the Granville grays was found to vary widely from one observer of normal color vision to another. However, the cross-over value of reciprocal color temperature for any one observer serves to characterize his color vision in an approximate but useful way. The value (of reciprocal color temperature) required in a 10° field for red-green balance is tentatively taken as a measure of the yellow pigmentation in the lens of the observer's eye. Similarly, the value required in a 2° field for red-green balance of the Granville grays is a measure of both lens and macular pigmentation. The difference in these two values (value for 2° field minus value for 10° field) is tentatively taken as a measure of the macular pigmentation of the observer.

The tentative measure of lens pigmentation afforded by the Granville grays correlated well with the age of the observer, but the tentative measure of macular pigmentation showed no correlation with age. Neither measure showed significant correlation with the color of the iris or of the hair. Of the 39 persons studied, eleven were female.

The color of the eyes of all the observers ranged from blue through hazel, light brown, brown, dark brown, to almost black; hair color ranged from ash blond through red, light brown, brown, dark brown to black. It was interesting to note that among the "red-red" observers—those with the least lens pigmentation—a number had heavily pigmented skin, irises, and hair.

Results of the tests were compared with four statistical definitions of a standard observer. The comparison showed that the three standard observers compiled in recent years were not superior for the 2° observation to the CIE standard observer recommended in 1931. However, data on a specific age group for the 10° standard observer developed by Dr. W. S. Stiles[4] of the National Physical Laboratory in England agreed very well with the average of the actual observers in the same age group in the present experiment.

Further work is scheduled to obtain color responses on textile and vitreous enamel samples. Data derived from these studies will be correlated with the work now being performed by Dr. Stiles in England and the combined results will be evaluated for a possible revision in the 1931 CIE standard observer.

[4] *Interim report to the Commission Internationale de l'Eclairage, Zurich, 1955, on the National Physical Laboratory's investigation of colour-matching*, by W. S. STILES, Optica Acta **2**: 168. 1955.

PROBLEM SOLVING ON THE HIGH-SPEED COMPUTER

Large-scale digital computers are helping the National Bureau of Standards carry out its fundamental program of research on properties of matter and methods of measurement with increasing speed, efficiency, and thoroughness. As knowledge of the computer's capabilities becomes more widespread, its use is being extended to more and more of the Bureau's work—from basic calibration services to complex studies of nuclear properties.

Moreover, the growing indispensability of high-speed computers, both to management and to scientific and engineering research generally, is clearly shown by the variety, extent, and importance of the problems that have been solved on the Bureau's computers. These problems come from every major field of physical science and technology, from statistical analysis, and from government and business administration.

At present, projects are serviced at the rate of about 150 per year, up to the limit of machine time available. Submitted by the Bureau's laboratories and by other Federal agencies, these range from "single-shot" problems, requiring a run of only an hour or two, to comprehensive programs carried out on a continuing basis for several years at a time. From 1950 to 1957 such problems were solved on the Bureau's home-built SEAC; in 1957 an IBM computer, type 704, was acquired. In addition, at the request of other agencies, the computation laboratory programs problems for NORC, UNIVAC, and other machines outside the Bureau.

The problems worked on the Bureau's computers illustrate not only the increasing number of fields in which the potentialities of the digital computer are being exploited, but also the wide range of computational techniques now available. In some cases, as in geometrical optics, the mathematics is essentially elementary. Here the main contribution of the computer is its great speed; but this also permits the inclusion of refinements that lead to better as well as faster results. Solution of systems of ordinary linear differential equations and of many partial differential equations is now almost a routine matter. More sophisticated procedures are found, for example, in studies of radiation penetration which apply Monte Carlo techniques and methods for solving integral equations; in calculations of crystal lattice constants, in which the coefficients of 3-dimensional Fourier series are determined; and in evaluating government contract bids which apply the techniques of linear programming. Still other methods are illustrated in an extensive program for calculating thermodynamic properties of materials and in the handling of large masses of data for payroll calculations. These and other problems, selected from those solved or now being calculated at the Bureau, are discussed further below.

GEOMETRICAL OPTICS

Essentially, the only way to design a lens system of the kind found in an aerial camera or telescope is by ray tracing. This consists in selecting a number of light rays emanating from some object point, determining by elementary geometry the path of these rays through the lenses, and finding their intersections with the plane of the final image or photographic plate. The deviations of these intersections from the desired image point furnish a measure of the quality of the lens system. The procedure may then be repeated for other object points and possibly for light of other wavelengths. Also, the parameters of the optical system—lens separations, curvatures, and indices of refraction—may be varied to improve the sharpness of the images.

For each choice of parameters, the number of arithmetic operations may run into millions, making use of a high-speed computer mandatory. A computer also has the advantage that it can handle skew rays—those not lying in a plane through the optical axis—as easily as rays that do lie in such a plane; in ray tracing by hand, skew rays are usually avoided as too difficult. As a result, the solutions provided by the digital computer are more thorough and accurate.

The principal application of automatic computers to such problems at the Bureau has been to compare the images formed by series of proposed lens designs in order to select the one best suited to a particular purpose. The computer output is automatically converted to graphical form, thus showing directly the appearance of images of point sources. In addition, ways are being studied for adapting methods of lens-system design to a fuller exploitation of computer capabilities. Results of such studies should be of use to the optical industry as well as to the defense establishment.

Ray-tracing computations were begun at the Bureau in 1950, when SEAC was put in operation, and are now on a continuing basis under the sponsorship of the Air Force. The construction and testing of prototype photographic objective lenses has become so expensive that a major computing effort is justified in order to assure that only optimum designs are actually built.

THERMODYNAMICS, STATISTICAL MECHANICS

For the past 7 years, the computation and thermodynamics laboratories have been engaged jointly in the development of high-speed computer techniques for calculating thermal properties of materials. Needs of research on propulsion systems provided the original stimulus for this project, but the computed data have a far wider range of application. Thus far most of the work has dealt with gases, and the results are in the form of tables of various thermodynamic and transport properties over a range of pressures and temperatures. Among the properties included are specific heat, entropy, heat content, vapor pressure, sound velocity, viscosity, and Prandtl number. With the aid of such tables it is possible, for example, to calculate the amounts of heat generated or other details on the course of chemical reactions inside a combustion chamber and the thrust of the resulting jet.

Since they form the starting point for many other calculations, the ideal-gas thermodynamic functions (for atoms, atomic ions, molecules, molecular ions, and radicals) were the first to be programmed. Programs were then developed for calculating (1) equations of state based on a virial representation of data of state, (2) gas-imperfection corrections to the thermodynamic properties for compounds and mixtures of fixed composition, and (3) equilibrium compositions and properties for chemically reacting gaseous systems.[1]

One phase of the work is summed up in NBS Circular 564, which contains data for air, argon, carbon dioxide, hydrogen, nitrogen, oxygen, and steam.[2] Plans are being considered for applying the same techniques to a systematic calculation of thermal properties for all atoms and their ions at temperatures up to 1,000,000°K.

A few of the other projects in thermodynamics, recently completed or still in progress, are concerned with calculation of improved molecular energies and wave functions, and a related study of self-consistent fields; calculation of collision integrals used in transport theory; evaluation of triple integrals for entropy calculations; and calculations to test the value of exchange integrals in molecular computations.

COLOR COORDINATES

Use of the standard CIE-chromaticity[3] coordinates for describing colors has the advantage that the coordinates can be obtained from spectrophotometer measurements of the light and do not depend on color judgments by the human eye. However, for industrial purposes the widely used Munsell system of color coordinates, based on perceived value, hue, and chroma, has the advantage that equal increments in the coordinates correspond to equal perceived differences (at least, within the range of normal individual variation). In the work of the Bureau's photometry and colorimetry laboratory it is therefore frequently necessary to translate the more easily measured CIE-chromaticity coordinates into the more directly useful Munsell system.

Since no usable mathematical formula is known for the relation between the 2 systems, the conversion must be based on direct experimental comparison of spectrophotometer measurements with estimates of color spacing by human observers.[4] For purposes of computer calculation, the results of such comparisons by the Optical Society of America[5] for about 5,000 discrete points of a grid in "color space" are being punched on cards. For colors corresponding to points other than these grid points, the conversion will be made by 3-dimensional interpolation between the values at adjacent grid points.

[1] Mechanized computation of thermodynamic tables at the National Bureau of Standards, by J. HILSENRATH and J. H. WEGSTEIN, in Proceedings of Conference on Thermodynamic and Transport Properties of Fluids, Institution of Mechanical Engineers, London, July 1957 (in press).

[2] Nat. Bur. Stand. Circ. 564, *Tables of thermal properties of gases*, by J. HILSENRATH and others, 1955.

[3] "CIE" stands for Commission Internationale de l'Éclairage (International Commission on Illumination).

[4] Prelimary report of the O.S.A. Subcommittee on the spacing of the Munsell colors, by S. M. NEWHALL, Journ. Opt. Soc. Amer. **30:** 617. 1940.

[5] Final report of the O.S.A. Subcommittee on the spacing of the Munsell colors, by S. M. NEWHALL, D. NICKERSON, and D. B. JUDD, Journ. Opt. Soc. Amer. **33:** 385. 1943.

To convert CIE-chromaticity coordinates for a single color to Munsell coordinates and to check the results, requires about 30 minutes by hand calculation. From trials of the program now being prepared for the digital computer, it is expected that the same operation will be performed on this machine in about one-hundredth of that time. A few minutes must also be allowed for setting up the computer, but this is negligible when a considerable number of conversions must be made.

SATELLITE CALCULATIONS

Working in cooperation with the Naval Research Laboratory, the Bureau is engaged in programming and computing for a number of satellite problems. The most important of these relates to the determination of upper atmosphere properties. Thus, by combining recent high-altitude rocket measurements with observations of the rate of change of period for the first Russian satellite (Alpha 2), it was possible to obtain reasonably good values for the atmospheric density at altitudes up to 400 km. At 200 km the results agree well with typical earlier estimates, but at 400 km a density 40 times greater was found. One consequence of this finding is to reduce estimates of satellite lifetime by the same factor for orbits with a perigee (i.e., minimum) altitude near 400 km. Other projects deal more directly with satellite lifetime and with the satellite's final dying period and point of impact. A theoretical investigation on the "interpretation and ambiguity resolution" of Minitrack observations is also under way.

In still another project, the computation laboratory has prepared a program for an approximate satellite ephemeris (or table of positions), using the basic equations provided by NRL. The program is designed for rapid calculation of the position of the satellite in a form convenient for use by Minitract stations and tracking radars. The program first integrates the equations of motion, with atmospheric drag included, and then transforms the satellite position to spherical coordinates fixed in the earth. In accordance with the aim of providing a quick, approximate table of positions, the precession of the orbit plane and the rotation of the line of apsides are included in a phenomenological form in the second part of the program. The printed output gives the latitude and longitude of the satellite, as well as its position relative to a number of observing stations, at intervals of 1 minute. The printout may be restricted to any specified range in latitude and longitude.

RADIATION PENETRATION

Computations on radiation penetration form one of the very large computer projects at the Bureau. This work stands out both for the magnitude of the operation and for its scientific and practical value. The results are directly useful in fundamental physical research, radiology, reactor design, and evaluation of effects of nuclear weapons.

The problem is to find out what happens to a beam of radiation when it traverses bulk matter. The particles in the beam—gamma-ray photons, electrons, neutrons, or others—collide with atoms of the matter and then are absorbed or scattered into different directions, often with ejection of particles or photons from the atoms; scattered and ejected particles can then enter into further collisions. The specific problem is to determine the number of particles at a given depth of penetration and moving in a given direction with a given energy.

There are two main approaches to this problem. The Bureau's nuclear physics laboratory has made contributions to each method.[6] In the first, the desired distribution is expanded into series with respect to two of the three independent variables, and the coefficients are found to satisfy certain linear integral equations. These are approximated by systems of linear algebraic equations that prove to be of a type that can be solved recursively. The other method is an application of the Monte Carlo technique, which consists in setting up a numerical analogue to the situation under study.

The complexity of the problem arises from the many possible ways in which the radiation and atoms may interact and from the complicating effects of special conditions—for example,

[6] A descriptive summary is given in *Penetration and diffusion of gamma rays*, NBS Tech. News Bull. **40:** 144. Oct. 1956. For further technical details see, for example, *Penetration of X- and gamma-rays to extremely great depths*, by U. Fano, Journ. Res. NBS **51:** 95. 1953. RP 2439; *Penetration and diffusion of X-rays: calculation of spatial distribution by polynomial expansion*, by L. V. Spencer and U. Fano, Journ. Res. NBS **46:** 446. 1951. RP2213; *Reflection and transmission of gamma radiation by barriers: semianalytic Monte Carlo calculations*, by M. J. Berger and J. Doggett, Journ. Res. NBS **56:** 89. 1956. RP 2653.

different shielding materials, source geometries, energy distributions of incoming particles, and boundary conditions at the interfaces between media. The computations thus far apply mainly to gamma rays, but increasing attention is being given to electrons.

CRYSTAL STRUCTURE

Crystal structure calculations, based on X-ray diffraction measurements, are a powerful tool for determining the arrangement of and distances between atoms in crystalline solids. Results of such calculations at the Bureau supply a steady stream of information for solid state physicists, chemists, and crystallographers.

When a beam of X-rays impinges on the regular array of atoms in a single crystal the rays are diffracted to form a pattern of isolated spots as detected, for example, on a sensitive screen. Information about the crystal structure is obtained from the positions and intensities of these spots. However, except in the simplest cases, this cannot be done without extensive calculations.

The procedure is based on the relation that exists between the diffraction pattern and the density distribution of the electrons that surround the atoms in the crystal. When the electron density distribution is expressed as a 3-dimensional Fourier series, each coefficient (called a "structure factor") in the expansion is a complex number that represents the intensity and phase of an individual spot in the diffraction pattern. Since only the intensities of the spots can be measured, additional assumptions based on chemical experience must be made. The computing methods enable any such assumption to be tested, and various devices have been developed to avoid excessive trial-and-error steps. Also, the computer is being used to evaluate methods of determining crystal structure without the need for conjectures based on chemical experience; such methods would be highly impractical without the use of high-speed computers. Since the atoms are located at the centers of electron clouds, their positions can be determined from the electron density distribution. The computer is also used to refine the results of previous calculations by determing the corrections required by improved experimental data.

When a crystal is ground into powder, the diffraction pattern becomes a series of concentric rings. From the location and intensities of these rings it is possible to identify the chemical composition of the crystal, and this technique is now widely used in industry. The ring pattern is related to the spacings between planes in the various systems of parallel planes that pass through atoms in a single crystal. Such spacings, called "d-values", are computed from results on single crystals and serve as indices for identifying different materials. This computation is then done in reverse, using d-values obtained from Bureau laboratory measurements to correct the structure constants.[7]

PROCUREMENT BID EVALUATION

The analysis of bids to determine the "low bidder" among potential contractors is more involved than first appears. In the case of Government procurement bids there are an average of 20 bidders, each of whom may have different sliding scales relating prices and quantities, may quote different prices for work done at different plants, may set minimum or maximum quantities, may be able to supply goods only to certain Government depots, or may accept an award only if he also receives—or does not receive—the award on some other bid. Also to be considered are the requirements of the various Government supply depots and the transportation costs from each potential plant to each depot. Additional complications enter when the Government furnishes raw materials, for example, textiles for uniforms.

Not all bids involve all of these difficulties, but often they are sufficiently complex that it takes months to analyze them. Even then, rough judgments must be substituted in part for exact calculations—unless the assistance of a high-speed computer is obtained. The speed, accuracy, and thoroughness of computer evaluation of bids assure prompt action and impartiality to the bidder and the least possible cost to the Government.

Methods for applying computers to this task have been developed by the Bureau for the

[7] *X-ray diffraction patterns for identification of inorganic solids*, NBS Tech. News Bull. **37:** 189. 1953. Results on crystal powders are published as Nat. Bur. Stand. Circ. 539, *Standard X-ray diffraction powder patterns*, by H. E. SWANSON and others. Volumes 1 to 7 have appeared (1953-1957) thus far; they are available from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. at 45 cents per copy for volumes 1–5 and 40 cents per copy for volumes 6 and 7.

Department of Defense over the past several years,[8] and a total of about 150 bid problems have thus far been analyzed. The basic problem is of the type known as a "transportation problem" which, in turn, is one kind of problem in linear programming. The Bureau's methods are based on the simplex method of G. Dantzig as modified for the transportation problem. With experience in its use, the technique has been made more versatile, so that many of the complicating factors can be taken into account in a single run of the computer (requiring only a few minutes). Previously, separate runs were needed for each complicating factor over and above the basic transportation problem pattern.

PAYROLLS

In January 1956 the Bureau adopted a mechanical pyroll system using punched-card equipment to compute and assemble in finished form the payroll for its nearly 3,000 employees as well as various personal service reports. This system has proved definitely superior to the former hand operation; however, certain phases of the operation are still too time-consuming. It is therefore planned to explore the possibility of achieving greater flexibility and efficiency by utilizing a commercial high-speed computer. To give some idea of the magnitude of the task the operation will be required to provide minimum reports under 10 different heads: payroll for personal services, check issue and statement of earning cards, time cards, devision total payroll control, bond schedule, bond purchase list, employees cumulative earnings report, labor distribution report, annual individual pay record, and withholding tax statement. It is expected that the results of this study, now under way, will also be of interest to other Government agencies and to private organizations.

TRAFFIC TRENDS

A somewhat different type of problem arising in Government administration is illustrated by a project recently completed for the Bureau of Public Roads. This problem involved the relative accuracy of 4 proposed methods for predicting changes in traffic patterns. Accurate anticipation of trends in traffic distribution would clearly help in planning more effective road and highway networks. The computer was used for calculating predictions by the various methods and for comparing the results with data obtained by a home-interview sampling technique in the Washington (D. C.) metropolitan area in 1948 and 1955. It was estimated at the outset that 25 million unit computations would be required; on the very optimistic allowance of 10 seconds per computation, this would require about 35 man-years for completion by hand methods. The actual computer time was 30 hours, which includes additional computations not considered in the original estimate.

TECHNOLOGICAL PHYSICS

The many computer projects that may be grouped under the heading of technological physics can be represented by those on stresses in a wall foundation, fire resistance of T-Beams, and gas tube characteristics. In the first of these, wall-foundation stresses are computed for given values of the length and height of the wall and the unit shortening due to shrinkage. This involves the solution of a biharmonic partial differential equation.

In the project on fire resistance, better information is sought on the relative fire-endurance performance of various reinforced concrete structures. Calculations are being made of the heat flow on the cross section of a T-Beam in contact with furnace fires. Results are expressed in terms of the time required to reach a certain predetermined temperature at various points on the cross section.

Considerable simplification of the process of designing cold cathode gas tubes for optimum performance is expected as an outcome of the project on gas tube characteristics. Voltage-current static characteristics are being computed from a system of differential equations together with data on gas properties, electrode materials, and tube geometry. Interest centers on the critical negative slope region which determines the tube's breakdown characteristics. These results will permit the theory to be compared with new experimental measurements.

Also, increasing use is being made of digital computers in the calculations needed in calibrat-

[8] *SEAC determines low bidder*, NBS Tech. News Bull. **38**: 179. 1954. For further technical details see *Experiences with the bid evaluation problem*, by H. BREMER, W. HALL, and M. PAULSEN, Nav. Res. Logist. Quart. **4**: 27. 1957.; *Linear programming in bid evaluation*, by E. D. STANLEY, D. P. HONIG, and L. GAINEN, Nav. Res. Logist. Quart. **1**: 48. 1954.

ing measuring instruments and reference standards. Examples are the calibration of thermometers and gage blocks. An investigation of more general significance has grown out of work on problems associated with the measurement of human hearing. In this project, mechanical impedances are calculated on the basis of a method of measurement developed by the acoustics laboratory for determining the resistive and reactive components of the impedance of the human head and mastoid, or of other high mechanical impedances.[9]

MATHEMATICAL TABLES

The development of the high-speed computer has not made the use of mathematical tables obsolete, but it has changed some of the characteristics that are expected of them. For use in computer operations, "skeleton" tables are useful, giving values to many significant figures and accompanied by auxiliary functions for calculating intermediate values. Tabular material covering only a few pages can thus replace tables that formerly occupied several volumes. Moreover, those without access to a large scale computer still need tables of the elementary functions and an increasing number of the higher functions—for example, confluent hypergeometric, spheroidal, and Sievert functions.

To meet these new needs, the Bureau is preparing a *Handbook of Mathematical Tables*[10] which will include graphs and text material as well as tables. There will be 28 chapters including tables of mathematical constants, powers and roots, elementary and higher transcendental functions, and basic tables for combinatorial analysis, numerical analysis, and statistics. The text material will give for each function the important mathematical properties that are useful in computational problems. With considerable help from the Bureau's computer, the preparation of the volume is now well advanced.

The *Handbook* is sponsored by the National Science Foundation, and its contents are being determined by Bureau staff members with the assistance of a Committee on Revision of Mathematical Tables appointed by the National Research Council. The primary aim is to include a maximum of useful information within the limits of a moderately large volume (about 1,000 pages), with attention to the needs of scientists in all fields.

Apart from work on the *Handbook*, which was started within the past year, the computation laboratory has been producing individual mathematical tables of general utility ever since SEAC was put into operation. Among those recently completed are tables of L-shell conversion coefficients, exponential integrals for complex arguments, modified Airy integral, and Coulomb wave functions over the range of interest in current nuclear research.

PROGRAMMING TECHNIQUES

Before a problem can be set into a computer, it must be programmed, a task which is performed by the Bureau's computation laboratory or by personnel of the originating section or agency. Programming for a new problem may require anywhere from a few hours to several months; then the machine may do its work in minutes or it may take hundreds of hours. When later a similar problem is submitted, the old program can often be adapted to the new data without much delay. It is thus important to accumulate a library of program routines and subroutines that may be assembled like standard parts to fit as wide a range of problems as possible. In addition, the possibility of using the computer itself in working out programs is being actively studied and promising results have already been obtained.

[9] *Mechanical impedance of the forehead and mastoid*, by E. L. R. CORLISS and W. KOIDAN, Journ. Acoust. Soc. Amer. **27:** 1164. 1955.

[10] *Handbook of mathematical tables*, NBS Tech. News Bull. **41:** 94. June 1957.

PROCESSING PICTORIAL INFORMATION ON DIGITAL COMPUTERS

Exploratory experiments in manipulating the information content of pictures[1] have recently been carried out on SEAC, the National Bureau of Standards Electronic Automatic Computer. With the aid of appropriate scanning and display equipment, the computer converts pictures into digital form suitable for input, processes the information according to some pre-arranged routine, and displays the results as a visual output. Experiments are being carried out by R. A. Kirsch of the Bureau's Data Processing Systems Laboratory to increase knowledge in the possible applications of high-speed electronic computers for picture processing.

The greatest impetus for the development of automatic data processing techniques has been the need to process at high speed alphabetical or numerical information. Ordinarily, such information exists already in digital form. If not, it can be translated into digits. In either case, it can be assembled manually to be fed into computers with suitable input devices. As a result of the great need for processing such conventional data, only recently has any attention been given to the use of general-purpose computers in in conjunction with special-purpose input devices for gathering unconventional types of data. In particular, there has been a lack of investigation into the use of digital computers for automatically gathering and processing information that naturally occurs in the form of pictures, diagrams, or other graphical configurations designed for visual use by human beings. Although considerable effort has been directed to such problems as recognition of printed alphabetical and numerical characters, this effort has been concerned mostly with the construction of specialized equipment for performing very specific functions. To provide more general information, the Bureau initiated a series of exploratory experiments involving the use of general-purpose digital computers to help understand the nature of pictorial information.

EQUIPMENT FOR INPUT AND OUTPUT

In order to feed pictorial information into SEAC, a simple mechanical drum scanning device is used to digitalize the information in a picture. The photograph to be scanned is mounted on a drum approximately $2\frac{1}{3}$ in. in diameter. As the drum rotates, a photomultiplier and a source of illumination mounted on a lead screw move parallel to the axis of the drum. The pitch of the lead screw is such that the photomultiplier moves 0.25 mm for each revolution of the drum. A mask in the optical system illuminates a 0.25-mm square, and a strobe disc produces optical pulses each 0.25 mm of drum rotation. Thus, the photomultiplier can examine the relative reflectance of each 0.25-mm square. Through the electronic circuitry of the scanner, a dark square on the picture is converted into a binary 1. A sufficiently white square produces a binary 0. The entire picture is scanned in 25 sec or less. Since the picture is 44 by 44 mm, it is converted into 30,976 binary digits, occupying 704 words of SEAC's memory.

To display a picture that has been fed into the computer from the scanner, a program was prepared to derive a pair of coordinate numbers for the position of each binary 1 in the picture stored in the memory. When decoded, the numbers produce a pair of analog voltages that are applied to the vertical and horizontal inputs of an oscilloscope, thus generating a visual display.

PROCESSING PICTURES ON SEAC

In pattern recognition the aim is to reduce the amount of information to the minimum necessary for recognizing one pattern from a group of patterns. In these experiments the approach was to develop a library of computational processes for simplifying patterns in order to obtain their most significant features. Preliminary experiments were concerned with determining those manipulations which would prove to be the most informative. The compilation of discrete routines for the performance of these elementary manipulations would provide the basis of a flexible system for simulating many widely diversified pattern identification logics. After determining the intended course of his pattern analysis, the programmer needs only to refer to this file and to select those routines which in combination will best serve his purpose.

Furthermore, it is possible for the analyst to sit at the computer console and to draw from

[1] For further technical information, see *Experiments in processing pictorial information with a digital computer*, by R. A. KIRSCH, L. CAHN, L. C. RAY, and G. H. URBAN, Proceedings of the Eastern Joint Computer Conference (IRE-AIEE-ACM), 1957.

this tape library several routines which he can select pragmatically after studying the results of any preceding operations, and thus guide the computer step by step toward recognition of the pattern being studied. Two forms of output can be distinguished in these routines—numerical data and transformed pictures. Numerical data can be read directly from the computer but pictorial information must be converted before it can be displayed by the picture output scope. The picture display routine is used in such cases.

One of the simplest routines in the library counts the total black area in a pattern. This program examines each bit in sequence and tallies when the bit represents a black area. Advantage is taken of the fact that in many patterns there will be numerous words that are all black or all white. By comparing whole words against constants of all zeros or all ones, much time is saved. The area counting process requires approximately thirty seconds on SEAC.

A routine was designed to count the number of objects in a picture. A black area is defined to be an "object" when it is completely surrounded by white areas. When a photograph containing 53 objects was fed into SEAC, the computer produced the correct count. Although some of the objects might be intuitively interpreted as two or more overlapping objects, this intuitive definition of an object was not used.

The routine for counting objects was not limited to counting solid, simply connected objects. When a picture of 9 abstract shapes were fed into SEAC, it produced the correct count even though the objects contained re-entrant profiles (i.e., a spiral) or were multiply connected (a letter B) or were interspersed among other objects. Another type of question that SEAC was programmed to answer involved evaluating the area of each of the objects counted. The area of an object was defined as the total black part of the object and did not include, for example, the white circle enclosed by a black annular area.

By combining the object-counting routine with the area-counting routine, it became possible to feed a picture into the scanner on SEAC to determine the number of objects having areas greater than a certain value. This eliminated specks of dirt from consideration. By a trivial modification of the program objects could have been counted and put into classes according to their areas.

SIMULATING COMPLEX PROCESSES ON SEAC

One of the most powerful features of a general-purpose computer with a picture input and output facility is the ability to study the performance of picture-processing mechanisms by simulating their behavior with a computer program. In this way mechanisms can be "tested" in some cases under conditions that would be difficult to create under laboratory conditions.

Automatic character-sensing (print reading) machines constitute a particularly important class of picture-processing devices. A study was undertaken of various logical schemes that have been proposed for the recognition of printed characters. A routine was written to study a character recognition logic based upon the identification of unique areas for each character in an alphabet. Under such a logical procedure for recognizing printed characters there are certain parts of each character which are black for that character and not for any other character. These unique areas serve to identify the characters.

The routine that was proposed for SEAC to study this recognition logic compared several photographs of different characters and determined which parts of the viewing matrix were (1) black for all letters concerned, (2) white for all letters concerned, or (3) sometimes black and sometimes white. This last area is the only part of the whole viewing frame that can be used to identify characters. Studies can now be made of characters in different fonts to determine the percentage of useful recognition areas that characterise the different fonts.

One shortcoming in this routine is the fact that it produces results that are very sensitive to rectilinear translations of the characters being analyzed. To overcome this difficulty, a SEAC program was prepared that calculates the center of gravity of any picture and then shifts the picture so as to move the center of gravity to any desired place in the matrix—usually the center. The overlapping areas routine is being used to study characters that have been oriented with the shifting routine.

EFFECTS OF SIMPLE OPERATIONS ON PICTURES

Programs were coded for SEAC to perform simple operations on each of the spots in a 30,000-spot picture. In each of these operations only the immediate neighborhood of a spot was considered by the computer in determining how

to operate on that spot. Simple routines of this type can readily be mechanized in the form of equipment, so experiments were performed to see whether such simple operations could produce important overall effects on a picture.

The first routine was one to add noise to a picture. It was coded so that random binary digits could be used to replace any spot in the picture. Another random number generating routine was used to determine which spots would be disturbed by the noise. The ability of the computer to simulate any desired type of noise distribution and to produce corresponding photographs enables quite elaborate studies to be made of the effects of noise upon ease of recognizing photographic information.

Another simple operation on pictures that produced unusual results was a kind of spacial differentiation. In this operation the computer investigates every black spot. If it is completely surrounded by eight other black spots, then it is converted to a white spot. In any other case, a black spot is written. The effect of such an operation is to preserve the boundaries of an image while erasing all the internal area. After doing this operation the computer inverts all the digits of the picture, that is, it converts black to white and vice versa. This constitutes one so-called "custer" of a picture. Even after custering 50 times, some traces of the image still remain. Additional trials show also that noisy figures seem to be stable under the custering operation.

OTHER PICTURE-PROCESSING ROUTINES

In addition to these routines some other simple routines have been written. These include routines to superimpose pictures, to smear pictures by translating and superimposing them, to magnify pictures so as to make their fine detail visible, to record pictures in permanent form on tapes and wire, and a routine to analyze a set of pictures to determine the number of spots that are always black or always white in the set of pictures.

These experimental picture-processing routines serve mainly to illustrate the variety of picture-processing procedures that can be performed on a general purpose facility like SEAC with its picture input and output. In addition to these experimental investigations, studies have been made of the feasibility of programming SEAC to demonstrate some picture-processing operations of considerable practical importance. In each of the following cases these studies have shown that SEAC could be programmed to do the operation described, although none of the programs has actually been written.

1. *Automatic coding of chemical and electrical diagrams.* For purposes of storage of information, pictorial representation of diagrams is very inefficient. For example, in a picture of the size used as SEAC input one could represent a simple transistor oscillator schematic or a structure diagram for the chemical compound phenol. But the useful information in each of these cases is no more than about 100 or 200 bits (binary digits), whereas 30,000 bits are needed in the picture. Thus a machine procedure to accept a photograph and produce a coded output for storage by a computer would result, in this case, in a storage capacity requirment of less than one-half percent of that needed for storing the picture.

2. *Simulation of logical procedures for recognition of printed characters.* If the more complex recognition schemes were programmed and analyzed, the result might be a saving in equipment construction costs since a simulated test might lead to radical changes in a piece of proposed equipment.

3. *Photogrammetric analysis of stereographic photographs.* The intended purpose here is to produce contour maps from photographic information. There is reason to believe that it may even be possible to do photo interpretation by machine. This would require that a program be prepared to recognize and classify objects in an aerial photograph in order to superimpose cultural information on a map or to provide various other types of overlays. Some of the problems encountered here border upon the subject that has come to be known as "pattern recognition," and further research is still needed in this area.

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